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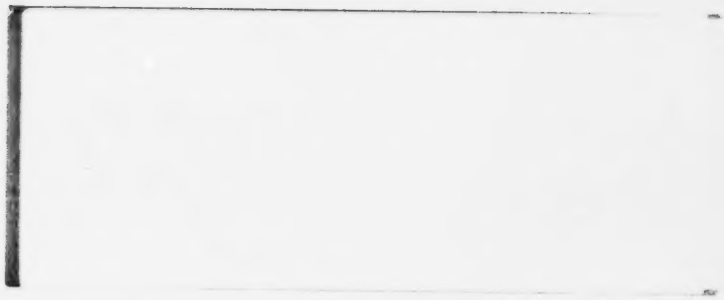

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AN INVESTIGATION OF SAFETY SHIELDS FOR SCHOOL BUS SEATS

Prepared for the
TRANSPORTATION DEVELOPMENT CENTRE
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By

L.A. Garland, D.K. Woods and D.A. Rolfe

T E S Limited

Ottawa, Canada

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

PROJECT TEAM

The project team for T E S Limited was composed of:

Mr. L.A. Garland, P. Eng.

Mr. D.K. Woods, P. Eng.

Mr. D.A. Rolfe, P. Eng.

The project team for Biokinetics and Associates Ltd. was composed of:

Dr. J.A. Newman, P. Eng.

Mr. A. St-Laurent, P. Eng.

The TDC Project Officer was Trevor N. Smith.

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17. Abstract

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A study of school bus accident and injury data found that school buses are the safest vehicle type per passenger kilometre and that serious injuries inside school buses are comparatively rare.

School bus seats were also examined in detail. The most significant change in seat design occurred in 1980, as a result of the implementation of Canada Motor Vehicle Safety Standard (CMVSS) 222, and these improved seats are expected to significantly reduce the injury rate in school bus accidents.

Two types of safety device were evaluated, a safety cushion and retrofit padding kits. All devices were subjected to laboratory testing to determine their ability to absorb impact loads. As well, the devices were installed in school buses for a field evaluation. The testing revealed that the latest type of school bus seats (CMVSS 222) provide excellent protection for passengers and that both the safety cushion and retrofit kits improved on this level of protection.

Although the safety devices improved protection, the need for such devices is not clear, especially when economic and technical problems associated with the devices are considered. Other areas for potential safety improvement are discussed including training and selection of school bus drivers, increasing the change over rate of pre CMVSS 222 school buses, and the use of seat belts.

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17. Résumé

Ce rapport décrit la recherche faite sur les dispositifs visant à augmenter la sécurité dans les autobus scolaires. Une étude statistique des accidents impliquant des autobus scolaires et les dommages qui en ont découlé a montré que, de tous les types de véhicules, ces derniers sont les plus sécuritaires, vu sous l'angle du nombre d'accidents par passager-kilomètre, et que le taux de blessures graves est relativement faible. L'étude a aussi porté sur les sièges dont la dernière révision importante remonte à 1980, en application de la norme NSVAC 222, et dont l'adoption devrait se traduire par une réduction sensible du taux d'accidents avec dommages corporels.

Le rapport rend compte de l'évaluation de deux sortes de dispositifs: le coussin portatif et le rembourrage en rééquipement, sur lesquels des essais en laboratoire ont été faits pour déterminer leur capacité d'absorption des chocs dynamiques. On a également procédé à des essais en service. Tous ces essais ont démontré l'excellente tenue du siège normalisé (norme 222) que rehaussent encore plus les deux dispositifs dont il est question.

Bien que ces dispositifs accroissent la sécurité, leur utilité réelle n'a pas encore été clairement déterminée surtout si on les considère du point de vut technico-économique. Le rapport fait aussi état des autres domaines susceptibles d'accroître la sécurité, soit la sélection et la formation des conducteurs d'autobus scolaires, le retrait accéléré des autobus non équipés de sièges normalisés et l'utilisation de ceintures de sécurité.

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SUMMARY

This report describes an investigation into the use of safety devices for school bus seats as a method of reducing passenger injuries.

A study of school bus accident and injury data found that school buses are the safest vehicle type per passenger kilometre and that serious injuries inside school buses are comparatively rare.

School bus seats were also examined in detail. The most significant change in seat design occurred in 1980, as a result of the implementation of Canada Motor Vehicle Safety Standard (CMVSS) 222, and these improved seats are expected to significantly reduce the injury rate in school bus accidents.

Two types of safety device were evaluated, a safety cushion and retrofit padding kits. All devices were subjected to laboratory testing to determine their ability to absorb impact loads. As well, the devices were installed in school buses for a field evaluation. The testing revealed that the latest type of school bus seats (CMVSS 222) provide excellent protection for passengers and that both the safety cushion and retrofit kits improved on this level of protection.

Although the safety devices improved protection, the need for such devices is not clear, especially when economic and technical problems associated with the devices are considered. Other areas for potential safety improvements are discussed including training and selection of school bus drivers, increasing the change over rate of pre CMVSS 222 school buses, and the use of seat belts.

TABLE OF CONTENTS

1.	INTRODUCTION	1
2.	METHODOLOGY	2
3.	SCHOOL BUS ACCIDENTS	3
	3.1 Accident Statistics	3
	3.2 Injury Causation	5
4.	SCHOOL BUS SEATS	7
5.	EVALUATION OF SAFETY DEVICES	11
	5.1 Description of Devices	11
	5.2 Laboratory Testing	14
	5.3 Field Evaluation	18
6.	DISCUSSION OF RESULTS	19
7.	AREAS FOR POTENTIAL SAFETY IMPROVEMENT	21
8.	RECOMMENDATIONS	24
REFERENCES		25

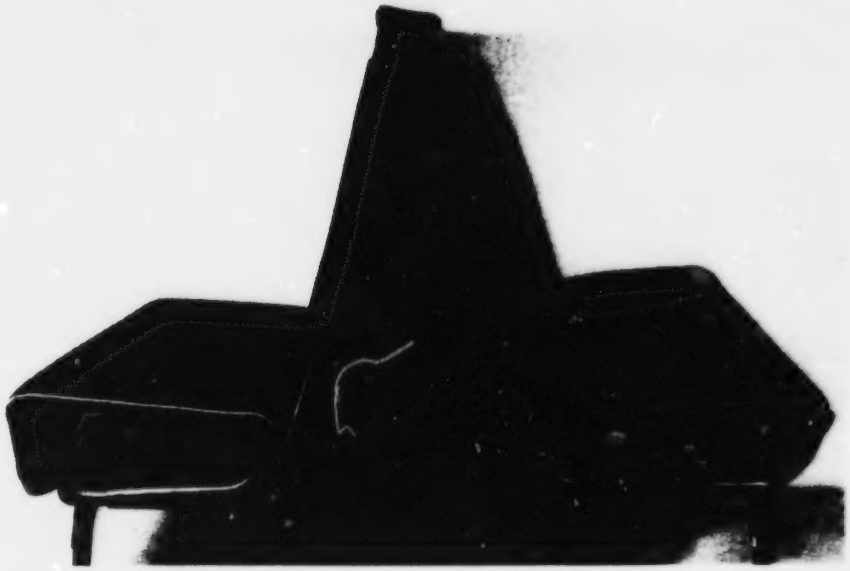
Appendix A People and Organizations Contacted
Appendix B School Bus Accidents and Passenger Injuries
Appendix C Laboratory Evaluation of Contemporary School Bus Seats

LIST OF FIGURES

Figure 1	Comparison of CMVSS 222 and D250.1 Type Seats	9
Figure 2	Katz Cushion Installed on D250.1 Type Seat in School Bus	12
Figure 3	T E S Retrofit Padding on D250.1 Type Seat - Rear View	12
Figure 4	T E S Retrofit Padding on D250.1 Type Seat - Front View	13
Figure 5	T E S Retrofit Kit on D250.1 Type Seat in School Bus	13
Figure 6	T E S Retrofit Padding on CMVSS 222 Type Seat - Rear View	15
Figure 7	T E S Retrofit Kit on CMVSS 222 Type Seat in School Bus	15
Figure 8	School Bus Seat Padding Layout	16
Figure 9	Head Acceleration Versus Impact Velocity	17

LIST OF TABLES

Table 1	School Bus Related Fatalities in the United States	4
Table 2	Fatality Rate per 160 Million Vehicle Kilometres	5
Table 3	Northrop's Injury Distribution Applied to 600 Canadian Injuries	6
Table 4	Estimated Injury Prevention Due to CMVSS 222 Seats	10



Typical School Bus Seats

1. INTRODUCTION

In July 1983, T E S Limited, in association with Biokinetics and Associates Ltd., was contracted by the Transportation Development Centre to investigate a design concept for a safety shield for use in school buses. The device under consideration was essentially a cushion, contoured in such a way as to allow it to be placed over a bus seatback, thus providing additional padding to the top and rear face of the seatback in a limited area.

The design concept for the safety shield was developed by Dr. M.S. Katz, a pediatrician who is also a Special Advisor to the Committee on Health Affairs of the Consumers' Association of Canada. The proposed safety shield was intended to allow individual parents to decrease the potential for injury to their children as a result of school bus accidents, by purchasing safety shields and requiring their children to carry them and install them on the bus seats daily.

As an alternative to the safety cushion, several retrofit devices were either designed or purchased. Both the safety cushion and the retrofit devices were subjected to laboratory testing and placed in service for a field evaluation.

This report discusses the results of investigations concerning the problem of school bus safety and the findings of the evaluation of the safety devices. Further, the report presents areas for potential safety improvement and recommendations arising from this work.

2. METHODOLOGY

In order to properly evaluate the potential for any device to reduce injuries to school bus passengers, it was first necessary to determine the extent and nature of injuries being experienced. As a result, the first part of this program was an extensive review of data on school bus accidents and injury causation. Numerous sources were accessed for information on this topic. Computer data bases were searched for published literature using the facilities of the Canada Institute for Scientific and Technical Information as well as Transport Canada's libraries. In addition, school boards, school bus operators, manufacturers and distributors were contacted for more personalized experiences. Further, Transport Canada personnel involved with school bus safety were interviewed, and visits were made to appropriate groups within both the National Transportation Safety Board (NTSB) and the National Highway Traffic Safety Administration (NHTSA) in Washington D.C. in order to benefit from their extensive experience within the United States. A more detailed listing of people and organizations contacted is given in Appendix A.

Most of the people contacted were very helpful, and in almost all cases, especially with researchers working in the area of school bus safety, there was general agreement with the findings of the literature survey concerning accident statistics and injury causation.

In addition to the portable safety cushion concept, methods of permanent padding (retrofit kits) for the seats were examined. The most feasible designs were then selected and either purchased or fabricated. Theoretical and practical comparisons were then performed between these safety devices and the safety cushion by arranging for laboratory tests and field evaluations.

3. SCHOOL BUS ACCIDENTS

3.1 Accident Statistics

It must be noted that current and/or exact statistics concerning school bus accidents and injuries in Canada do not exist. The latest information is for 1975 and is arrived at by inference and extrapolation from detailed or semi-detailed data for a particular region and time. Canadian statistics can however, be supplemented by somewhat better data from the United States, and where the data can be compared, there is close correlation. A more detailed treatment of accident statistics can be found in the Biokinetics and Associates Ltd. report which is included as Appendix B.

In Canada in 1975, there were 36,000 school buses in service (1). They averaged 88 kilometres of daily travel. There were 5.35 million students and 36.5% of these (1.95 million) were transported to and from school in school buses. The 36,000 school buses in service were involved in 2,150 accidents (roughly a 6% rate) which resulted in 1,300 injuries. Of these, 600 injuries were sustained by pupils inside the bus.

It has been estimated by Northrop et al. that in school bus accidents in which passengers are injured, an average of 1.4 passengers are injured per accident (2). Thus, the 600 injuries would have been sustained in approximately 430 accidents or 20% of the 2,150 total. Further then, in 80% of the estimated school bus accidents in 1975 there would have been no injuries to the passengers at all.

The estimated number of school bus related fatalities in Canada in 1975 was 17. Of these, 2 pupils were estimated to have been killed within school buses and 8 were estimated to have died as a result of being struck by a school bus and/or another vehicle while they were crossing the road to or from a bus. The remaining fatalities were persons other than school bus passengers. School bus related fatalities for the United States for the years 1977 to 1981 are given in Table 1.

The fatality data for both countries clearly indicates that a school bus is more dangerous to outsiders than to its occupants.

Gutoskie reports that, in 1975, school buses had an injury rate of 1.3 injuries per million vehicle kilometres versus an injury rate of 1.0 injuries per million vehicle kilometres for all vehicles (1). While this superficially indicates a higher injury rate for buses, when the statistics are viewed on a passenger kilometre basis, instead of on a vehicle kilometre basis, school buses are considerably safer than other vehicles.

YEAR	1977	1978	1979	1980	1981
Occupants of School Bus					
Drivers	1	6	5	2	3
Passengers	20	17	13	7	11
TOTAL	21	23	18	9	14
Pedestrians					
Struck by School Buses	44	48	50	35	35
Struck by Other Vehicles	19	35	25	11	9
Other	2	3	3	3	2
TOTAL	65	86	78	49	46
Occupants of Other Vehicles					
Drivers	66	95	77	56	58
Passengers	34	40	26	32	23
TOTAL	100	135	103	88	81
Bicyclists	8	3	6	4	3
GRAND TOTAL	194	247	205	150	144

Table 1 School Bus Related Fatalities in the United States (3)

The above statistics may be confusing, so to illustrate, assume that there are 20,000 pupils that are required to be transported an average of 10,000 kilometres to and from school per year. If the pupils are bused at 20 passengers per bus (which is a conservative figure considering that large buses can and do accommodate up to 72 pupils), 1,000 buses are required, which results in ten million vehicle kilometres travelled. Gutoskie's data then indicates that approximately 13 passengers would be injured (1.3 injuries per million vehicle kilometres).

If the same 20,000 students are transported in automobiles at 2 pupils per vehicle, then 10,000 automobiles are required, resulting in 100 million vehicle kilometres travelled. At a rate of 1.0 injuries per million vehicle kilometres, 100 people would be injured.

A comparison of the fatality rates for school buses with the fatality rates for other vehicles further demonstrates the superior safety record of school buses. Table 2 shows the fatality rates per vehicle type in the United States for the years 1975 to 1981. The rates are expressed on a vehicle kilometre basis. Had they been expressed on a passenger kilometre basis, they would have been even more in favour of school buses as previously illustrated.

Siegel et al. reported that between 1965 and 1969, school bus fatality rates were also lower than the fatality rates for airplanes and trains (4).

Thus, it appears from all published data, that school buses are the safest available mode of road transport of passengers, and that injuries sustained during the relatively few accidents which do occur are even more infrequent than the accidents.

YEAR	1975	1976	1977	1978	1979	1980	1981
School Bus Occupants	0.6	0.7	0.5	0.6	0.6	0.5	0.4
Commercial Bus Occupants	1.0	1.3	0.7	0.7	0.6	0.7	0.9
Combination Truck Occupants	1.2	1.4	1.4	1.4	1.5	1.5	1.5
Truck Occupants	2.1	2.1	2.2	2.3	2.4	2.1	1.8
Single Unit Truck Occupants	2.3	2.3	2.3	2.5	2.6	2.1	1.8
Passenger Car Occupants	2.5	2.4	2.4	2.4	2.4	2.5	2.4
Motorcycle Occupants	14.3	14.8	18.2	19.7	22.2	28.6	27.1
TOTAL	3.4	3.2	3.3	3.3	3.3	3.4	3.2

Table 2 Fatality Rate Per 160 Million Vehicle Kilometres (3)

3.2 Injury Causation

Most of the available Canadian school bus passenger injury causation data is from Multi-Disciplinary Accident Investigation (MDAI) reports. This limited data is from moderate to severe injury-producing accidents. It indicates that more than half of the injuries resulted from contact with seatbacks.

However, two points must be stressed. First, the MDAI reports are not representative of the average school bus accident, because in order for collisions to be investigated by MDAI teams, they must meet specific criteria, and as a result they tend to be much more severe than the average collision. Second, in all of the accidents, the buses were equipped with pre CMVSS 222 seats. Injury statistics of school buses with seats in compliance with CMVSS 222 do not exist at this time, however, significant reductions in injury severity are forecast. The significance of CMVSS 222 is explained in Section 4 of this report.

As detailed in Appendix B, the predominant source of injuries, in school buses with pre CMVSS 222 seats, was the seats themselves, especially the seatbacks. Impacting the seat caused from 70% to 90% of all injuries. The other sources of injury in decreasing order were side walls, seat legs, occupants and windows. Not surprisingly more than half of the injuries were to the head and face.

From the previously estimated figure of 430 injury producing accidents in 1975 and the number of injuries (600) sustained inside school buses, it is intuitive that most injuries were minor, since it would seem unlikely in an accident for only one or two passengers to be injured and for all other passengers to escape being injured, if the two injuries were severe or fatal. This corroborates the information received from school boards and bus operators. They indicate that the predominant school bus accident is the hard braking type where a standing passenger is thrown against a seat or barrier and is mildly injured.

Accidents where more than a few passengers are injured are rare, which accounts for the scarcity of data. It is interesting, that even in the more severe accidents, almost all injuries are Abbreviated Injury Scale (AIS) level 1 or 2 (minor or moderate). For an explanation of the AIS injury scale, refer to the report in Appendix B.

Northrop et al. have estimated the distribution of injury levels in fatal and non-fatal school bus accidents in the United States (2). Using Northrop's estimates on a pro rata basis and applying the resulting distribution to the 600 injuries in Canada in 1975 produces Table 3.

Table 3 shows that the 2 fatalities inside school buses in Canada in 1975, as estimated by Gutoskie, agree with Northrop's distribution very well. The table also shows that over 98% of injuries inside school buses were AIS level 2 or lower, further demonstrating that school buses are not major producers of severe injury.

AIS Injury Level	Northrop's Distribution (%)	Estimated No. of Injured Passengers
1	87.6	526
2	10.6	64
3	0.9	5
4	0.4	2
5	0.1	1
FATAL	0.4	2
TOTAL	100	600

Table 3 Northrop's Injury Distribution Applied to 600 Canadian Injuries

4. SCHOOL BUS SEATS

Since seats are the major injury causing component of school buses, a more in depth investigation of this area was carried out.

Parliament passed the Motor Vehicle Safety Act in 1970. The Act provides authority for the issuance of federal safety standards. They are intended for vehicle manufacturers who must certify that the vehicles met all the safety standards in effect at the time of manufacture.

Since 1971, over 30 Canada Motor Vehicle Safety Standards (CMVSS) have been issued that affect school buses. Of these, the one that should have the largest impact on injury reduction is CMVSS 222, "School Bus Passenger Seating and Crash Protection". It was enacted in 1979 and became effective as of September 1, 1980.

Prior to this, from 1971 to 1980, school bus seats were built in compliance with Canadian Standards Association (CSA) standards D250-1971 and D250.1-1975. CSA standards are voluntary standards, unless they are mandated by contract. Since the school bus manufacturers vigorously participated in preparing the standards, they were adhered to, however, the standards are essentially the documentation of the manufacturers' practices at the time of issue.

The seats in school buses manufactured from 1971 to 1975 were in compliance with CSA D250-1971, "School Buses". The sections of the standard relating to safety with respect to the seats were as follows:

- All seats shall be forward-facing and shall be securely fastened to that part or parts of the bus which supports them.
- The minimum centre-to-centre seat spacing shall be 68.6 cm.
- Backs of all seats of similar size shall be of the same width at the top and of the same height from the floor and shall slant at the same angle from the floor. The top portion of the frame of each seat, except the rear-most seat, shall be padded and covered.
- All metal frames shall have rounded corners and be free from sharp edges.

As a result of this standard, buses manufactured up to 1975 were equipped with seat cushions that could fly off during impacts and with thin walled tubular seat frames fastened to the floor with sheet metal screws. This resulted in seats becoming unhinged and seatbacks bending or breaking during accidents, thereby removing the only restraint available to a passenger, and encroaching into the survival space of other passengers.

The tops of the seatbacks were from 45.7 to 50.8 cm above the seat cushion. The frame was exposed, although the top portion was covered, and slightly padded. The back of the seatback was either metal or solid wood. The low seatback could theoretically allow passengers to fly over the seat in severe collisions, and/or inflict head and face injury by its very position. The seatback was also very hostile due to the lack of padding.

In 1975, standard D250 was revised and was renamed CSA D250.1-1975, "Large School Buses". Both D250 and D250.1 applied to school buses with 24 or more passenger seats. The changes to the standard were minor, with only the following paragraphs affected:

- All exposed tops and side rails of school bus passenger seats shall be padded extending to seat cushion level with energy absorption material sufficient to minimize injury producing impact forces. Back cushions shall be constructed so as to eliminate exposed screws or bolts, which contribute to vandalism of seats and their components.
- A passenger seat cushion retention system shall be employed to prevent the passenger seat cushion from disengaging from the seat frame in the event of an accident. Each seat cushion retention system shall be capable of withstanding a vertical static load equal to a minimum of 5 times the weight of the cushion. The system shall also be capable of withstanding a forward or rearward static load equal to 20 times the weight of the cushion.

These changes resulted in seats where the seat cushion was firmly attached to the seat frame. The frame, however, was still prone to collapsing and/or breaking in an accident. The unspecific padding requirements induced manufacturers to add approximately 2.5 cm of foam to the top of the seat frame, completely covering the frame. As a result, the seatback heights were raised to 50.8 to 55.9 cm above the seat cushions. Approximately 1.3 cm of foam was added to the rear face of the seatback, and the whole seatback was covered with vinyl covering. The seatback thickness was increased from 5.1 to 6.4 cm. The D250.1 seats, although better, still had the same basic deficiencies as the D250 seats.

In 1980, CMVSS 222 became effective. The requirements of CMVSS 222 are detailed in the report in Appendix B. Basically, CMVSS 222 mandated that school bus passengers be confined from the front and rear, by non-collapsing and well-padded surfaces.

The standard attempts to ensure that passengers are not catapulted forward and not injured by whiplash, by requiring a minimum seatback height. The seatback height requirement translates into the seatback being 63.5 cm high, from the undeflected cushion. The standard also attempts to reduce the possibility of passengers falling into the aisles and incurring injuries due to striking the floor and/or seat legs, by limiting the spacing between seats. The specific force/deflection requirements on the impact surfaces ensure, that in a crash, passengers will normally encounter energy absorbing surfaces. This has resulted in the strengthened seat frame and seatback being completely enclosed by approximately 5.0 cm of high density energy absorbing foam material. Figure 1 shows a CMVSS 222 seat and a D250.1 seat.

Data clearly documenting the benefits of CMVSS 222 seats does not exist at this time. However, in 1980, Northrop et al. did a very extensive study on the effectiveness of FMVSS 222 (2). CMVSS 222 and its U.S. counterpart FMVSS 222 are very similar. The only major difference is that FMVSS 222 requires small buses (gross vehicle weight rating less than 4,536 kg) to be equipped with seat belts, while CMVSS 222 does not.

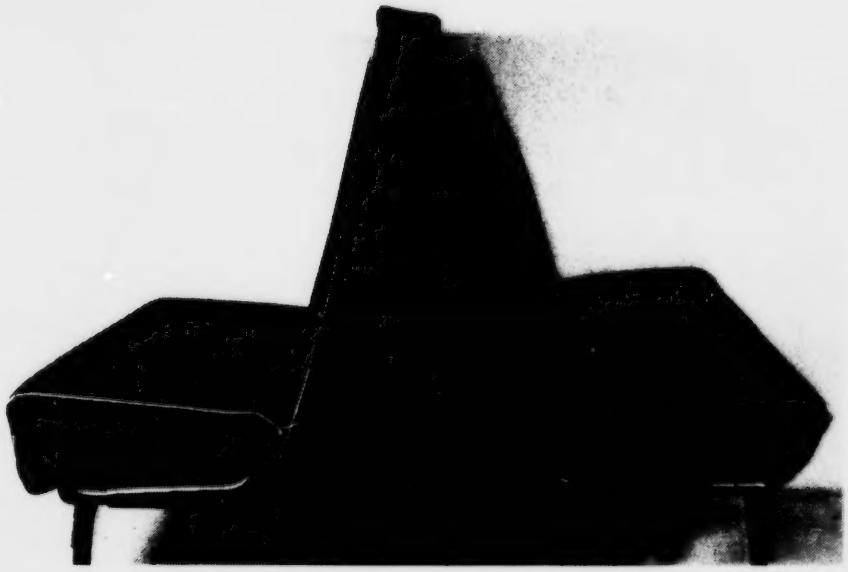


Figure 1 Comparison of CMVSS 222 and D250.1 Type Seats

The study, as highlighted in Appendix B, estimates that FMVSS 222 (or CMVSS 222) will produce a dramatic reduction in the number of injuries incurred inside school buses.

Table 4 shows the results of applying Northrop's injury reduction estimates to the 600 injuries in Canada in 1975 and shows the number of injuries which would have been prevented had the school buses been equipped with CMVSS 222 seats.

An argument can be made that since some of the prevented injuries in Northrop's study are attributed to passengers wearing seat belts and since belts are not required in Canada, the number of prevented injuries is optimistic for Canada. However, small school buses make up less than 10% of the total school bus population. Therefore, Table 4 should be representative of the number of injuries preventable in Canada.

The statistical data shows that school buses were a relatively safe mode of transportation, even with the pre CMVSS 222 seats. In addition, it has been estimated that post CMVSS 222 seats should have a major impact in further preventing and reducing injuries inside school buses. Currently, approximately two thirds of the school buses in use in Canada are still equipped with pre CMVSS 222 seats.

Zimmerman concluded in 1979 that fairly standard materials are available that would allow the retrofit of school bus seats to allow them to meet at least the dynamic portion of CMVSS 222 (5). He describes a commercial retrofit kit manufactured by Easy-Way Products. It consists of 1.3 cm of Ensolite padding that can be taped to the seatback or modesty panel and covered with an envelope like vinyl cover. The retrofitted seat satisfied the CMVSS 222 knee and head form criteria on the seatback but not on the seatback or modesty panel rails. To meet dynamic criteria on the rails required 3.2 cm of padding.

AIS Injury Level	Number of Injured Passengers		Number of Injuries Prevented
	1975 Statistics	1975 Statistics with CMVSS 222 Seats	
1	526	193	333
2	64	16	48
3	5	4	1
4	2	1	1
5	1	1	-
Fatal	2	2	-
TOTAL	600	217	383
Percent of Pre CMVSS 222	100%	36.2%	63.8%

Table 4 Estimated Injury Prevention Due to CMVSS 222 Seats

5. EVALUATION OF SAFETY DEVICES

Two types of safety shield device were considered for evaluation, a safety cushion and retrofit padding kits. The safety cushion (a prototype of which was supplied by Dr. Katz) is not permanently attached to the seat whereas the retrofit kits are installed under the vinyl seat cover.

5.1 Description of Devices

The Katz device is a vinyl covered cushion, approximately 33 cm wide, 35 cm high and up to 13 cm thick, shaped to allow it to rest on the top of a bus seatback. Figure 2 shows the device installed on a D250.1 type seat. It is attached to the seat with Velcro strips, securing it against accidental bumping but allowing it to be removed.

As noted in the introduction, the concept of a portable, individualized, safety shield/cushion, was intended to allow concerned parents to contribute to the safety of their own children without the necessity for school board or government level action. It was intended to be purchased individually, carried daily by a child, and placed by the child over the back of the seat immediately in front of him, in whatever school bus he happened to be riding.

The retrofit devices consisted of a commercially available padding kit and two padding kits designed and constructed by T E S Limited. The commercial kit was manufactured by Easy-Way Products of Cincinnati, Ohio and contained a piece of 1.3 cm thick foam and a vinyl seat cover. This kit is intended for seats manufactured prior to 1975, without padding on the rear of the seatback. The foam is placed over the rear, sides and top of the seatback and the seat cover fits snugly over the foam and seatback. No claims are made by the manufacturer as to specific levels of protection offered or compliance with any standards.

The primary design goal of the kits produced by T E S Limited was to provide the maximum amount of protection possible with minimal inconvenience and intrusion into the passenger space. In addition, simple installation and low cost were important considerations. In order to be able to accommodate almost all types of school buses in Canada, two versions were produced. One was for a D250.1 (1975-1980) type seat and the other for a CMVSS 222 (post 1980) type seat.

For the older style of seat, the height of the seatback was increased by 7.6 cm and 2.5 cm was added to the thickness of the upper seatback. These dimensions were selected to approximate the height and degree of protection offered by the CMVSS 222 style seat. A foam with a similar density as the existing material was chosen as the most appropriate material. Figures 3 and 4 illustrate the retrofitted foam (dark coloured material) placed on the existing seatback padding. A slip cover of similar material and construction to the original was fabricated and installed. Figure 5 shows the modified seat installed in a school bus with the Katz device installed on a normal D250.1 seat in the background. The increased height of the retrofitted seat is readily apparent but the thicker seatback is not easily noticed.

Figure 2 Katz Cushion Installed on D250.1 Type Seat in School Bus

Figure 3 T E S Retrofit Padding on D250.1 Type Seat - Rear View

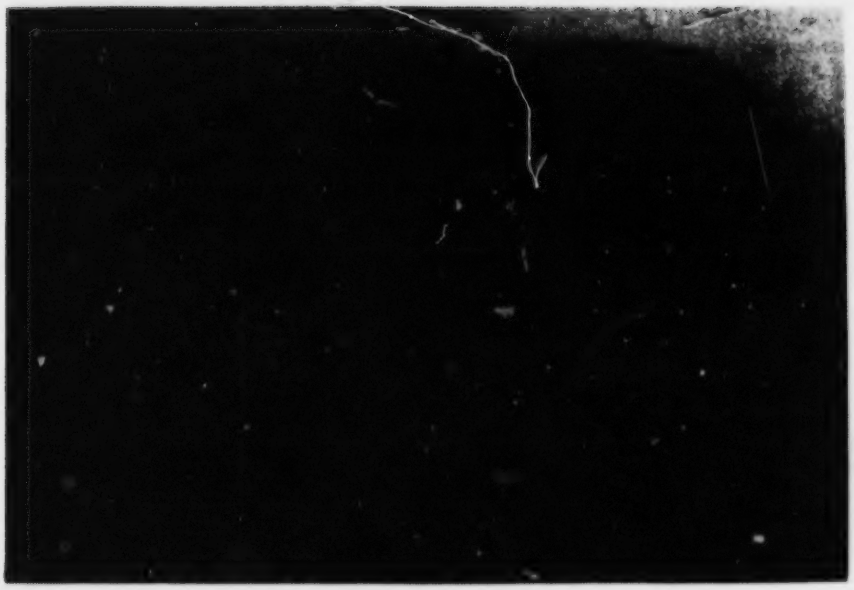


Figure 4 T E S Retrofit Padding on D250.1 Type Seat - Front View

Figure 5 T E S Retrofit Kit on D250.1 Type Seat in School Bus

The newer style of seat (CMVSS 222) was felt to be of optimal height, therefore, the additional padding for this seat consisted of a single piece of 2.5 cm thick foam extending 20 cm down from the top of the seatback on the rear face of the seatback. This padding is shown in Figure 6. The complete seat with cover is shown installed in a schoolbus in Figure 7. The exact layout of the padding for the two retrofit kits designed by T E S Limited is shown in Figure 8.

5.2 Laboratory Testing

Comparative testing of various combinations of seats and safety devices was performed at Biokinetics and Associates Ltd. The subject seat was impacted at a measured velocity by an instrumented headform. The headform, as well as containing an accelerometer, was modified in the area contained by the eyes and nose to receive a frangible face form. This face form has been designed to simulate the facial bone structure and fractures at similar forces to the human face. For a more detailed explanation of the apparatus, refer to the report in Appendix C.

The seat to be tested was secured in the test rig with the rear of the seatback facing upwards. The headform was dropped on the seatback from increasing heights until fracture of the frangible face form resulted or the maximum height of the test device was reached. The maximum deceleration during impact was recorded for all tests.

The results of this testing enable a comparison to be made between the energy absorbing characteristics of the various seats and devices for a range of impact velocities. However, because the energy absorbed by seat frame deflection was not measured, these results cannot be compared directly to the expected performance of the seat assembly under actual accident conditions.

The results of the laboratory testing reveal that, as expected, the performance of all seats was proportional to the thickness of the padding. The T E S Limited retrofit kits and the Katz cushion both improved the performance of the seats, the Katz cushion to the greatest extent. Further experimentation with the stiffness of the foams utilized would allow improvement and optimization of the performance of both devices.

Three seats failed to provide protection up to the level of the remainder of the seats. They were the pre 1975 seat, the pre 1975 seat with the Easy-Way retrofit kit and the pre CMVSS 222 (D250.1) seat. The rest of the seats offered protection in the range of speeds most often encountered in school bus accidents.

The performance of the various seats and safety devices is shown in Figure 9. In general, as noted previously, the greater the foam thickness, the greater the attenuation of the impact forces. However, the improvement in performance of the CMVSS 222 seat over the pre CMVSS 222 (D250.1) seat is noteworthy since the overall thickness of the seats is similar. The difference in performance is accounted for by changed foam density and internal arrangement of the foam and seat frame. This raises the possibility that further improvements in seatback crash performance could be achieved with little or no increase in cushion size.

Figure 6 T E S Retrofit Padding on CMVSS 222 Type Seat - Rear View

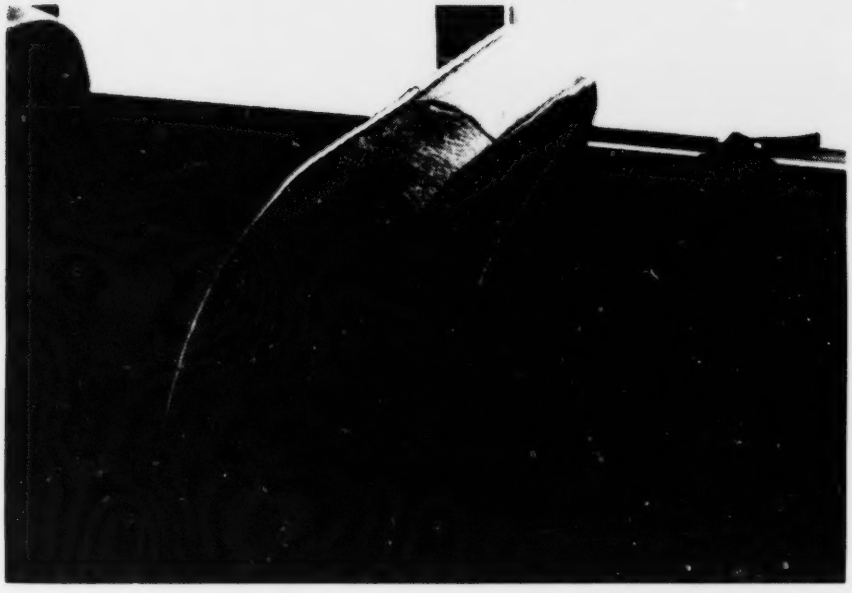


Figure 7 T E S Retrofit Kit on CMVSS 222 Type Seat in School Bus

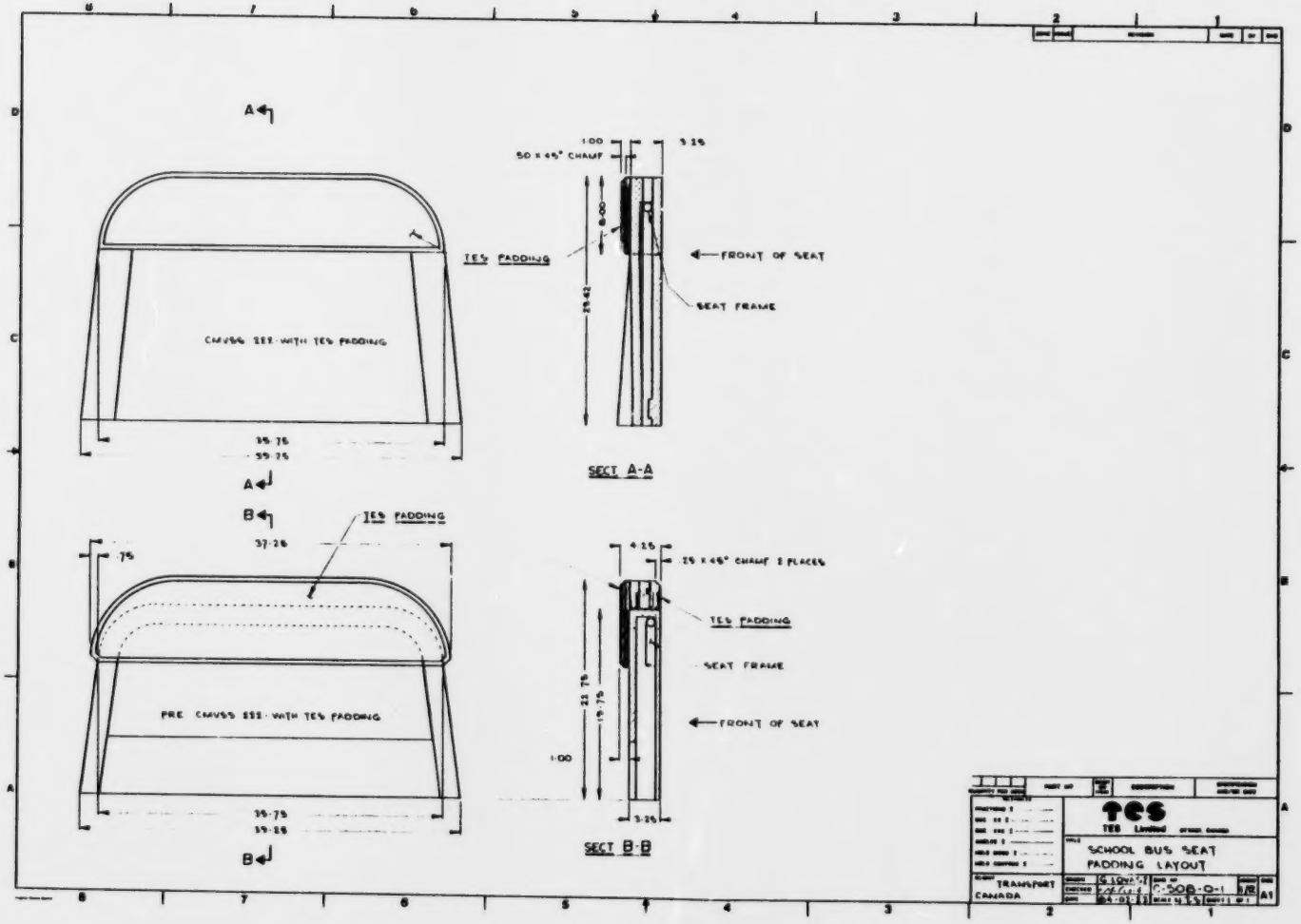


Figure 8 School Bus Seat Padding Layout

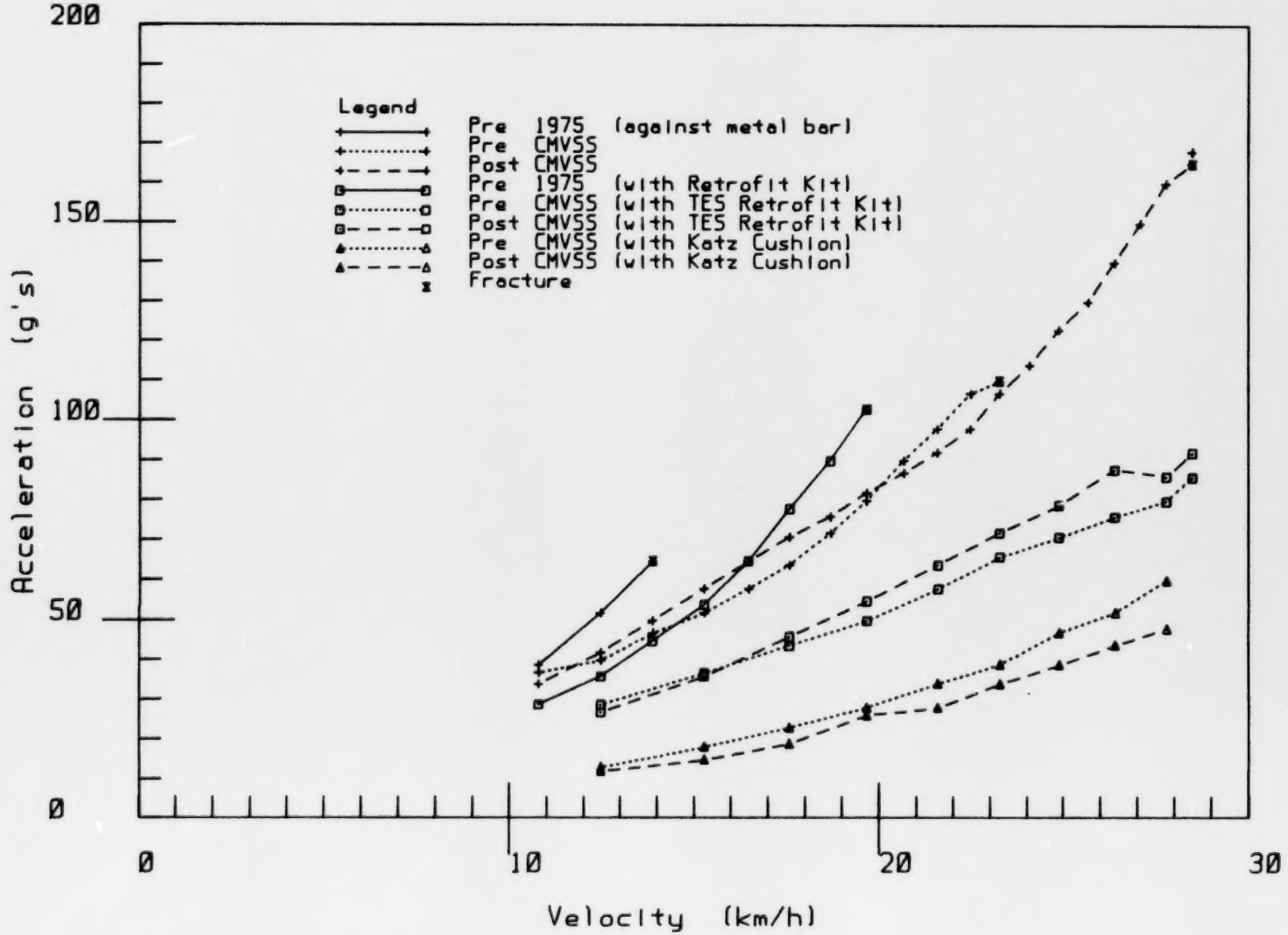


Figure 9 Head Acceleration Versus Impact Velocity

5.3 Field Evaluation

An assessment of the practicality of the safety devices in an actual operating environment was conducted by arranging for a field evaluation program in conjunction with an Ottawa school bus operator, Travelways Limited. The Katz device and the T E S Limited retrofit kit for a D250.1 (1975-80) style seat were installed on one bus and the T E S Limited retrofit kit for a CMVSS 222 style seat was installed on another bus. Figures 2, 5 and 7 show these devices installed on the buses.

After an evaluation period of close to a month, all concerned personnel at Travelways were interviewed including the drivers, the service manager and the safety supervisor. They were asked for their comments and reactions to the devices.

The consensus of opinions was that the retrofit kits passed almost unnoticed. Although the Katz device did not become detached, it was used as a cushion for resting on by the passengers in the seat immediately behind it. As well, it interfered with the passage of students carrying lunches. The driver of this bus expressed a preference for the seat with the additional padding over the seat with the Katz cushion. The installation of all devices posed no difficulties for mechanics experienced with school bus interiors.

6. DISCUSSION OF RESULTS

As the accident data shows, the majority of school bus passenger injuries are caused by the seatback and are to the face and head. Thus, the safety devices are certainly addressing the correct area. The validity of the devices then becomes a question of practicality and necessity.

School buses are involved in very few accidents (only 6% of all school buses in service have accidents in one year) and of these accidents only 20% result in any injuries at all to bus passengers. Further, of these injuries only 2% are more than moderately severe. In addition, all of this data is based on pre CMVSS 222 seats, which are forecast to further reduce injuries to approximately 40% of previous levels.

While it must be noted that all of these figures are estimates rather than hard data on current performance, even with a large margin of error, one could still not define the school bus passenger injury rate or severity level as high. This is not to say that any attempt to further reduce injuries is unjustified, however, when combined with the practical difficulties associated with a safety shield/cushion approach, the data suggests that the justification for detailed development work on such a device is not warranted.

Some of the technical difficulties associated with carrying the safety cushion device through to a production item are as follows. The device must fit easily over the seatback, as it is intended for daily use by children. At the same time, however, it must remain in place relatively securely so that bus motion or the activities of the passengers in the seat on which it is mounted, do not dislodge it. These somewhat divergent requirements are further exacerbated by the fact that there are various seatback thicknesses currently in use. Further, while the seatback width is approximately 90 cm, or three times the width of the prototype cushion, the top corners are rounded with a radius of 15 cm, leaving a horizontal top surface only 60 cm wide in the centre of the seatback. This would apparently preclude the use of three safety shields on one seat and, even in the case of two being used, would result in their being side by side in the centre of the seatback. This would not be adaptable to the current practice of carrying three small children per seat and would require even two passengers to sit as close together as possible in the middle of the seat in order to be lined up with their respective safety cushions.

A further difficulty arises when the effect on the forward seat passenger(s) is considered. The portion of the safety cushion which extends down in front of the seatback would have to serve as a headrest for that seat's passenger and presumably not interfere with his comfort. While this may be achievable as an engineering design goal, even given the wide range of passenger heights liable to be encountered, the aspects of hygiene associated with headrests on seats in public vehicles usually require removable, washable, or disposable covers which are replaced frequently, often as frequently as every trip. This, of course, could be seen as a problem in this case from both viewpoints, that of the owner of

the device, or that of the person who must of necessity use it as a headrest. When combined with the likelihood of such a child portable device being occasionally dropped into mud or slush, the problem becomes even more significant.

Other potential problem areas associated with the use of a portable safety cushion such as peer group pressures against its use or misuse by unruly students are beyond the scope of this study, but should not be lightly dismissed.

Most of the difficulties associated with a safety cushion device do not apply to the retrofit kits. As well as being permanent, they offer the advantages of minimal intrusion into passenger space, almost no change in appearance and, consequently, they are unlikely to be targets of vandalism or misuse. In addition, the level of protection offered by the retrofit kits has been shown to be very similar to that provided by a safety cushion.

The decision to install retrofit kits would rest with individual school bus operators or school boards. There are several possible methods of arranging for the installation of the retrofit kits. However, if they were to be marketed on a commercial basis, it would appear that the costs of production and inventory would have to be offset by subsidies or a guaranteed market to make the venture a viable proposition. Thus, interest would have to be demonstrated by the school boards. This seems questionable in view of the scarcity of injury producing accidents.

If interest is expressed by a few school boards, plans of the kits could be developed and sold or provided to them. All materials used in the manufacture of the kits could be purchased by the school boards and the kits assembled and installed locally. The cost could be partially offset by installing the seat kits when the seat covers are due for normal replacement. The cost of supplying a 72 passenger (24 seat) school bus with retrofit kits can be estimated at approximately $1000 based on a cost per kit of $40. The installation costs would be in the order of $500 per bus, producing a total cost of $1500 per bus. The retrofitting operation could be accomplished in one working day by two mechanics.

The value of the safety devices in injury reduction is difficult to assess. However, it is unlikely that the fitting of either safety cushions or retrofit padding kits would cause as significant a reduction in injuries as the use of CMVSS 222 seats or that safety devices would be fitted on all buses. Therefore, although there would undoubtedly be some reduction in injuries attributable to the safety devices, the point at which diminishing returns for increased cost is to be accepted would have to be considered, in detail.

An additional consideration in assessing the effectiveness of safety devices is raised by the findings of the laboratory testing of the school bus seats. If a CMVSS 222 seat can protect passengers in collisions with speeds of up to 40 to 50 km/h (and very few school bus accidents occur above these speeds), then the need for additional padding is doubtful. A retrofit kit on a D250.1 seat could be beneficial, however, the number of buses in service with this type of seat is steadily decreasing as more buses equipped with CMVSS 222 seats are produced.

7. AREAS FOR POTENTIAL SAFETY IMPROVEMENT

The findings of the literature review indicate that the causes of school bus accidents, in decreasing order, are as follows: school bus driver error, other driver error, bus defects, environmental conditions, and other vehicle defects. Once an accident occurs, the major injury causing devices within the bus, in decreasing order, are as follows: seatbacks, side walls, seat legs, other occupants and windows. Further, the majority of injuries to bus passengers are to the head and face.

Thus, the problem of further improving school bus passenger safety can be approached on two fronts. First, reduce the number of accidents and, second, reduce the injury severity during those accidents which do occur.

The intent of this program was to address, in detail, specific solutions to the latter of these two areas which would reduce head and face injuries sustained during impact with the seatback. While the accident data shows this to be the major area of injury causation, problems with the suggested solutions, as detailed in the previous section of this report, coupled with the eventual effect of increasing usage of CMVSS 222 seats, led to the consideration of other areas which might have a potentially larger and more cost-effective impact on school bus passenger injury reduction. Some of these areas are discussed here.

Better Selection and Training of School Bus Drivers - In Canada, the licencing and training of drivers falls under the exclusive jurisdiction of the provinces. As a result, there is no national school bus training program similar to that laid out by the United States Department of Transportation, Standard 17, "Pupil Transportation Safety". Standard 17 establishes the minimum requirements for the operation and maintenance of school buses, and the training of personnel.

Since injuries are a result of accidents and the majority of school bus accidents may be a result of errors by the school bus drivers, a better selection and training of school bus drivers should have major positive effects.

Other Driver Behaviour - Other drivers contribute significantly to the number of school bus accidents. Various techniques for modifying the behaviour of other drivers have been tried. Some of these, such as an eight light system (four amber warning lights which flash before the bus stops and four red lights which flash to prohibit passing when bus motion has stopped and children are boarding or disembarking) have apparently been used to effect. Recent studies by the Ontario Ministry of

Transportation and Communications investigated some of these techniques and the results of this research should be followed up.

Increasing the Change Over Rate of Pre CMVSS 222 School Buses - Some school boards are currently limiting the age of their school buses. The age limit is as low as three years in some cases. It is not exactly clear if the school boards are limiting the age of their buses specifically because of CMVSS 222 or because they feel that older school buses inherently have more mechanical and structural defects which contribute to accidents. However, if a school board limits the age of its school buses, the data indicates that the safety record of that school board will improve, partly due to accident rate reduction, and partly due to the introduction of more CMVSS 222 seats.

However, the national school bus safety record will not be significantly affected if only a few boards limit the age of their buses, since the older school buses will simply be used by other school boards which have no limit. Thus, only a nationally implemented program to limit the age of school buses will have a meaningful effect.

A reasonable age limit might be seven or eight years. Presumably, this would not only reduce the number of accidents due to bus defects but would also increase the proportion of school buses with CMVSS 222 seats and eliminate the older seats from the bus population.

Seat Belts - Seat belts (in this context the term seat belts refers to lap belts only) are not mandatory for school bus passenger seats in Canada. Seat belts are, however, mandated in small school buses in the United States. They also have been recently approved, on an after market basis, for large school buses by the NTSB. The recommendation, however, stresses that the installation of seat belts must be accompanied by "a strong and continuing commitment to educate students in the importance of using the seat belts and using them properly". This reflects the often expressed view that seat belts could be used as instruments of vandalism or as potentially dangerous weapons by unruly children. On the positive side is the experience of school boards in Canada, such as Etobicoke, who have utilized seat belts, coupled with a proper training and supervision program, to benefit.

The NHTSA on the other hand, has denied three petitions from the Physicians for Automotive Safety asking the agency to require seat belts in all new school buses and/or to require that all buses be equipped with seat belt anchorages. The last petition was denied in August 1983.

Clearly, the use of seat belts in school buses is not a black and white issue. The proper use of seat belts will reduce injuries and deaths in severe crashes, however, there is a possibility that even if they are properly worn, the use of lap belts without torso belts may result in more head and neck injuries than would otherwise occur in buses equipped with CMVSS 222 seats only. This is a result of the "jack-knife" like motion that would be imposed on the partially restrained body. This motion may cause the head to strike the seatback in front at a less favourable angle and velocity than it would have, had the passenger not been partially restrained.

In addition, it is not known if CMVSS 222 seats are strong enough to withstand the seat belt loads in severe accidents, since the belts may apply point loads to the frame, for which the frame was not designed. This assumes that the belts are anchored to the seat, however, even if the belts are anchored to the floor, they may result in loadings to the seat which will cause deformation or failure.

These are some of the questions concerning seat belt usage which require specific answers. Transport Canada is planning to investigate and test seat belts in school buses in the near future. Hopefully, this will help to provide further information on the subject.

8. RECOMMENDATIONS

Retrofit padding kits have been demonstrated to be technically feasible as well as offering measurable benefits in crash protection. The requirement for additional protection as well as the marketability of these kits (as well as the safety cushion) remains questionable. Available information on school bus safety indicates that greater potential for improvements in safety would be obtained by investigation of the areas discussed in the previous section. Some specific recommendations for work which might be undertaken are as follows:

Driver Training - Investigate the possibility of applying some derivative of the US DOT Standard 17, "Pupil Transportation Safety", to the Canadian school bus driver selection and training process. This would require government interaction at both federal and provincial levels. However, it would have the single largest potential for improvement of school bus safety.

Other Driver Error - Follow up on the results of research studies into the effectiveness of warning systems (such as the eight light warning system) in improving the behaviour of other drivers in the vicinity of school buses.

Bus Defects - Conduct a program to define the age distribution of the current school bus population in Canada and to establish the costs involved with limiting bus age. This type of program, if economically viable, would serve the dual purpose of reducing bus defects due to age and increasing the percentage of CMVSS 222 seats in use.

Information Dissemination - One area which does not fall within the domain of improving bus safety, but which nonetheless should be considered for future work, is the dissemination of information concerning school bus operation and safety to parents, school boards and government agencies. The statistics clearly show the degree to which school buses outperform other modes of transport (particularly the family car) and, if parents were made aware of this, it might help to reduce the concern about school bus safety which is periodically expressed. In addition, such information might be used to bring pressure to bear in the areas of both driver training and school bus age limitation.

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5. Zimmerman, "Tests and Materials for School Bus Retrofit Applications", Proceedings of the Twenty-Third Annual STAPP Car Crash Conference, San Diego, California, 1979.

Appendix A

People and Organizations Contacted

PEOPLE AND ORGANIZATIONS CONTACTED

School Boards

Carleton Board of Education Nepean, Ontario (613) 820-1820	Safety Officer	S. Morrel
Ottawa Board of Education Ottawa, Ontario (613) 563-2212	Safety Officer	M. Peterson
Protestant School Board of Greater Montreal Montreal, Quebec (514) 483-7295	Director of Student Services	S. Conrad
Etobicoke Board of Education Etobicoke, Ontario (416) 626-4360	Transportation Officer	F. Martin
Scarborough Board of Education Scarborough, Ontario (416) 296-7614	Operations Supervisor	J. Mazanik

Bus Operators

Travelways Limited Ottawa, Ontario (613) 741-3600	Service Manager Safety Supervisor	R. Godin G. Raycraft
Travelways Limited Toronto, Ontario (416) 294-5104	Claims Manager	W. Carter
Charterways Transportation Ltd. Nepean, Ontario (613) 820-7146	Operations Manager	P. Borlangit
Charterways Transportation Ltd. London, Ontario (519) 679-9150	Safety Officer	M. MacAlpine

Bus Manufacturers and Distributors

Bluebird Bus Company Brantford, Ontario (519) 759-4960	Engineer	M. Barke
Thomas Built Buses of Canada Ltd. Woodstock, Ontario (519) 539-1225	Director of Engineering Engineer	A. Callaby G. Black
Wellies Corporation Windsor, Ontario (519) 945-6311	Sales Manager	A. Susko
Leeds Transit Sales Ltd. Ottawa, Ontario (613) 731-5908	Sales Manager	B. Leblanc
Capital Bus Sales Ottawa, Ontario (613) 741-3600	President Sales Manager	J. Charlebois R. Desjardins

Canadian Government

Transport Canada Road Safety and Energy Operations Ottawa, Ontario	P. Gutoskie R. Myers G. Farr B. Hendricks J. Bain	(613) 992-0077 (613) 995-7293 (613) 995-7293 (613) 993-9851 (613) 992-2174

United States Government

National Traffic Safety Board
Washington, D.C., USA

Safety Officer	L. Smith	(202) 382-6564
Safety Officer	Dr. B. Loeb	(202) 382-6564
Chief, Accident Division	A.L. Schmieg	(202) 382-6852
Accident Division	H. Wakeland	(202) 382-6852

National Highway Traffic Safety Administration
Washington, D.C., USA

Safety Officer	D. Soule	(202) 426-0085
Engineering	R. Williams	(202) 426-2264

Appendix B

School Bus Accidents and Passenger Injuries

SCHOOL BUS ACCIDENTS AND PASSENGER INJURIES

- A LITERATURE REVIEW -

Submitted to

TES Limited

Prepared by

Andre St. Laurent
Biokinetics and Associates Ltd.
Ottawa, Canada

September, 1983
Document R83-14A

TABLE OF CONTENTS

INTRODUCTION	1
BUSES	3
PUPILS	4
ACCIDENTS AND INJURIES	5
ACCIDENT CAUSATION	7
INJURY CAUSATION	13
CMVSS 222	22
EFFECTS, POTENTIAL AND REAL OF CMVSS 222	28
CONCLUSIONS	33
RECOMMENDATIONS	36
REFERENCES	38
APPENDIX 'A'	41

INTRODUCTION

Concern has been expressed that a school bus is not a particularly safe environment for children to commute in.

TES, under TDC sponsorship, has commissioned Biokinetics and Associates to review school bus accidentological data. To this end, a literature search has been conducted and herein virtually all available and pertinent data has been gathered and assessed.

From the onset, it is clear that children in school buses are commuting in what is perhaps THE safest mode of transportation; very few accidents occur and when they do, the vast majority of injuries tend to be limited to cuts, scrapes and bruises to the facial area.

It should be noted that an exact description of bus accidents and injury statistics is impossible. Many provinces in this country simply cannot relate even the number of school buses in service for pupil

transportation (1)[1]. National statistics are arrived at by inference to and extrapolation from detailed or semi-detailed data available for a particular region (1,2) and a particular time. For these reasons and because of the fact that accident and injury samples were subject to varying sampling criteria, some discrepancies will be found in the data presented. For instance, Multi-Disciplinary Accident Investigation (MDAI) teams tend to investigate and report only on the more severe accidents (resulting in an amplified and distorted accident severity picture).

This is not to say that different accident studies present contradictory data. The reported discrepancies tend to be more a matter of degree in terms of number of passengers involved, number of injured and severity of injury.

Fortunately, one factor that mitigates these sources of inaccuracy is the fact that both Canada and the U.S.A. have published fairly detailed estimates of the Pupil/School Bus situation for the year of 1975. (1,2) That is, before the inception of MVSS 222.

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[1] Numbers in parenthesis designate references found at the end of the paper.

It is interesting to note the similarity of the scenarios for both countries. (Table 1) This is not too surprising; both countries enjoy similar lifestyles, driving styles and, to a great extent, climate. Of course, lower population (9.4:1) and population densities will require that Canada own more school buses per capita and that they will likely be less filled than their U.S.A. counter parts.

BUSES

In Canada, in 1975, there were approximately 36,000 school buses in service. They averaged fifty five (55) miles of daily travel or: 10,200 miles/year per bus. The number of buses in service in the U.S.A. is 7.5 times that of Canada, or: 270,000 buses. Table 1 summarizes these findings.

TABLE 1

DESCRIPTION	CANADA	U.S.A.	RATIO
Total Number of Buses	36,000	270,000	7.5:1
Miles/Bus/Year	10,200	10,270	1:1
Total Vehicle Mile/Pupil	366.3×10^6	$2,700 \times 10^6$	7.4:1

PUPILS

In Canada in 1975, there were 5,354,543 pupils enrolled in schools across the country of which 36.5% (1.95×10^6 pupils) were transported to and from school by bus. (3) In the U.S.A. 45×10^6 students were enrolled in public schools with 87% (21.5×10^6 pupils) riding school buses. The average distance travelled by pupils in the U.S.A. is 3.6 miles with a standard deviation of 1.5 miles.

Table 2 summarizes the school bus users statistics:

TABLE 2

DESCRIPTION	CANADA	U.S.A.	RATIO
Number of Pupils Enrolled	5.35×10^6	45×10^6	8.4:1
Number of Pupils Riding School Buses	1.95×10^6	21.5×10^6	11:1

In summary, it would appear that the U.S.A. has a slightly higher percentage of school going population than Canada and that they also tend to put more children in their buses than do their Canadian counterparts.

ACCIDENTS AND INJURIES

In Canada, in 1975, there were an estimated 1,300 pupil injuries as a result of an estimated 2,150 school bus collisions. Of these, 600 were injured inside the bus. There were, for the same period in the U.S.A., an estimated 8,500 injuries which are associated with an estimated 48,000 school bus accidents. Six thousand (6,000) were to pupils; of which an estimated 93% (5,700) were injured inside the school buses.

These injury figures are quite low when considered in the contexts of amount of pupil travel and other vehicle injury rates. Table 3 presents the significant statistics.

Compared to the number of buses operated in each country, it is observed that in Canada:

- The proportion of bus riding pupils is lower;
- The buses are less crowded;
- In every respect, injury rates are lower.

TABLE 3

DESCRIPTION	CANADA	U.S.A.	RATIO
Number of Accidents/Mile (Buses)	5.8×10^{-6}	8.5×10^{-6}	1.5:1
Riders Injured/Total # Riders	1.1×10^{-4}	2.65×10^{-4}	2.4:1
Injuries/Vehicle Mile	2.0×10^{-6}	2.3×10^{-6}	1.2:1
Injuries/Pupil Mile	1.0×10^{-7}	1.4×10^{-7}	1.4:1
Injuries/Passenger Mile (Automobile)	8.0×10^{-7}	1.0×10^{-6}	1.25:1
Passengers Injured/Total # of Passengers (all vehicles)		1.1×10^{-2}	

In 1974-75, in the U.S.A., there were 185 school bus related fatalities of which thirteen were pupils inside the bus. In Canada, there were seventeen deaths related to school buses. It is estimated that only two occured inside a bus.

By comparing injuries/mile for the pupils in buses to

"occupants" in all vehicles, it is observed that injury rates are eight times higher for the "occupants".

This is significant as the proportion of accident involved vehicles to all registered vehicles is only 60% higher for cars than for buses.

ACCIDENT CAUSATION

The typical bus accident occurs in daylight (82%), under clear weather conditions, on asphalt roads (71%), while the vehicle is travelling in a forward direction (52.9%). The peak accident times are between 8 and 9 a.m. and 4 and 5 p.m. (41%). These are the times when most buses are in operation. The peak months for school bus accidents are January and February (30%), mainly because, though weather conditions are good, the roads may be icy, slippery or wet and it is also within the peak September/June school bus utilization periods.

In 1971 Siegel et al,(5) suggest a descriptive profile for the majority of school bus accidents.

"They occur in daylight (94%) in clear (74%) weather, at a non-intersection (60%) urban location (61%) involving a collision between the bus and (73%) another moving motor vehicle." (5)[2]

In Canada, approximately 25% (1) of the school bus drivers involved in collisions committed a driving infraction; the most common being failing to yield right of way and speeding. It is interesting (or perhaps puzzling) to note that 48% of the case reports did not state whether or not the driver had committed an error. This may imply that school bus drivers are responsible for far more of the school bus accidents, as will be substantiated further on. The breakdown of the driver infractions reported in the study are listed in Table 4. The above data was derived from surveying approximately 3,600 accidents during the 1974-1975 period and was obtained through the Traffic Accident Information and Data System (TRAID).

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2 Percentage figures added by this author. They are from a 1968 report from R.W. Hull et al, from Southwest Research Institute as presented by Siegel et al.

TABLE 4

PERCENTAGE OF TOTAL REPORTED INFRACTIONS

DRIVER ERROR	CANADA	U.S.A.[3]
Fail to Yield Right of Way	26.8	20.0
Speeding	10.0	26.0
Misjudgement	8.6	12.0
Improper Turn	8.4	17.0
Following Too Closely	6.1	4.0
Careless Driving	6.0	1.0
Disobeying Traffic Sign	4.4	
Improper Passing	1.9	7.0
Driving on the Wrong Side of the Road	1.1	6.0
Other	26.0	7.0

Of all the drivers of vehicles colliding with buses, 27% are known to have commited an error of some type. Again, approximately half fall into the "not stated" category.

3 3880 accidents from Ohio, New Mexico and Iowa.

The data also revealed that 26% of the school buses involved in collisions had vehicle defects. The major defects noted in this sample were: faulty brakes: 40%, other: 30%, steering mechanism failure: 8.4%.

Analysis of forty-one reports from Multi-Disciplinary Accident Investigation (MDAI) teams corroborate the general findings of the TRAID files: In about 55% of the cases, driver error was found to be the major cause of collision. Other causal factors in MDAI reports include: other drivers (20%); bus defects (20%) and environmental conditions for the remainder (5%).

The differences between TRAID and MDAI data with respect to bus defects are attributed to the fact that MDAI teams conducted detailed post collision investigations.

The figures for school bus accident causes from TRAID and MDAI files are summarized in Table 5.

Gou and Steiner (4) report that in 1975, 26% of all buses in collisions in the province of Quebec had a mechanical defect of some sort. Incredibly enough, they report that for one particular company operating in Quebec, 80% of its vehicles were defective or dangerous.

In 1977, only one of 164 buses were found in good order and in 1978 still only one out of 115 vehicles were found to be in good order!

Fortunately, this appears to be an exception rather than the rule, for in many instances (e.g. Travelways in Ottawa), buses are inspected twice a year.

TABLE 5

CAUSE OF SCHOOL BUS ACCIDENTS

DESCRIPTION	U.S.A. (%)	CANADA TRAID (%)	CANADA MDAI (%)
Bus Driver Error	57.4	25.0	55.0
Other Driver Error	35.2	27.0	20.0
Total Driver Error	92.6	52.0	75.0
Bus Defects	1.6	2.6	10.0
Other Vehicle Defect	0.9	2.3	
Total Vehicle Defect	2.5	4.9	20.0
Driver Visibility	0.7		
Weather	0.1		
Road Conditions	0.1		
Total Environment	0.9		5.0
Not Identified	4.0		
	100.0	56.9	100.0

Causal factors for school bus accidents in the U.S.A. tend to follow those described for Canada. Table 5 presents the U.S.A statistics for 9,981 accidents from the states of Iowa, New Mexico and Ohio. Again, the major cause of accidents is bus driver error and where vehicle defects are present, brake failure is the primary cause. Vehicle defects for Canada and the U.S.A. are summarized in Table 6.

TABLE 6

DISTRIBUTION OF IDENTIFIED VEHICLES DEFECTS

DEFECTS	CANADA	U.S.A.
Brakes Defective	40.0	57.8
Wheel Came Off		24.1
Steering Mechanism Failure	8.4	6.0
Taillights Out/Obscured	4.2	
Tire Tread Insufficient	4.2	
Wheels/Suspension/Rear Axle Defective	3.2	2.4
Engine Control Defective	2.1	
Puncture/Blowout	2.1	1.2
Lights Defective	1.1	
Other	34.7	6.0
Loose Bus Seats		2.4

Finally, vehicle age does not seem to be a major factor in bus collisions. In Canada, it was found that the vast majority (88.8%) of the buses were less than ten years old. In the U.S.A., it was found that over one-half of the buses involved in an accident were four years old or less. It is likely that the oldest buses are kept as back up vehicles. Nevertheless, older buses tend to suffer from design deficiencies which may (and do) contribute to injury production, thus degrading overall school bus safety.

INJURY CAUSATION

Offending designs include hostile seats, structurally weak passenger compartments, and windows. These allow ejection or may cause lacerations, contusions or head, chest or knee injuries to a passenger.

In this country, data defining injury causation is unavailable from the TRAID file. MDAI reports do, however, provide a limited relatively well defined data set able to describe injury causation. It must be stressed that for an accident to be investigated by an MDAI team it had to meet certain specific criteria. Therefore, accidents in the MDAI files are not

representative of the average school bus accident, they are more severe.

Table 7 summarizes thirty cases involving over 1,000 passengers studied across Canada (4). It shows some statistics as to the cause of injuries and distribution.

TABLE 7

REGION	AIS-76[4]	% OF INJURED PASSENGERS[5]	% CASE
Seat Backs	1	33.6	80.0
	2	4.3	33.0
	3	<1.0	13.0
	4	<1.0	6.0
Stanchions	1	8.4	30.0
	2	<1.0	13.0
Broken Window/Glass	1	5.6	30.0
	2	1.0	12.0
	3	<1.0	9.0
Other Occupants	1	20.2	37.0
	2	2.3	17.0
	3	<1.0	10.0
	4	<1.0	7.0
	5	<1.0	3.0
	6	<1.0	3.0
Window Frame/Side Interior	1	11.7	27.0
	2	2.0	10.0
	3	<1.0	9.0
	6	<1.0	3.0
Exterior of Vehicle	6	<1.0	6.0
Loose Seats	1	9.3	27.0
	2	<1.0	3.0
	3	<1.0	3.0
	6	<1.0	3.0
Roof and Luggage Rack	1	5.4	13.3
	2	2.0	13.0
	3	<1.0	6.7

Passengers Total: approx 1,000
Cases Total: 30

$$\% \text{ Passenger: } \frac{\text{\# of Passengers of an "X" AIS}}{\text{Total \# of Passengers}}$$

$$\% \text{ Case: } \frac{\text{\# of Cases of "X" AIS}}{\text{Total \# of Cases}}$$

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4 Examples of AIS scores are given in Table 8.

5 Slightly over 100% as some passengers had more than one injury source.

The Abbreviated Injury Scale (AIS) is an injury coding procedure in which:

TABLE 8

AIS	DESCRIPTION	EXAMPLE
1	Minor	Lacerated Lip, Fractured Tooth
2	Moderate	Fracture of Body of Mandible (simple)
3	Serious	Eye Avulsion; Fracture of Mandible displaced, comminuted
4	Severe	Le Fort III fracture: entire Maxilla and 1 or more facial bones separated from brain case.
5	Critical	Brain stem contusion, diffuse brain injury unconscious for more than two and one-quarter hours.
6	Maximum Injury	Virtually unsurvivable; brain stem laceration, skull ring fracture.

For the purposes of this study, much of table 7 may be dismissed. Categories "EXTERIOR OF VEHICLE", "ROOF AND LUGGAGE RACK", are not associated at all with frontal collisions. Also less likely to be of concern are the categories: "BROKEN WINDOWS AND GLASS", "WINDOW FRAME AND SIDE-INTERIOR".

By far the most frequent injury causing object is seen to be the seat back. In 80% of the accidents, it was found that at least one passenger received a "minor" injury from the seat back. It was thus responsible for one-third of the injured passengers injuries. The seat back was also responsible in 33% of the accidents for "moderate" injuries.

The MDAI data are further substantiated by school bus injury data collected in New Brunswick between 1973 and 1977. This data, of poorer quality (sample size: 20 collisions), still asserts that 70% of the students sustained injuries as a result of body contact with the seat back in front of them.

Unfortunately, the number, or proportion of head, facial, thorax or knee injuries is not presented in either Gutoskie's (1) or Gou and Steiner's (4) report.

Between 1972 and 1976, the University of Toronto MDAI team found eleven accidents of sufficient severity to merit investigation. (6) Four of these were frontal collisions. One, an out of control bus struck a bridge parapet which penetrated to the third passenger seat. The bus driver and two passengers sustained AIS-2 level

injuries. "All other occupants had only minor bruises (sic)". In a second collision, a bus struck the rear of a stopped tanker truck producing: 66 inches of crush to the bus and three AIS-2 level injuries: one fractured mandible, one dislocated shoulder and one fractured nose with significant contusions. Merrit states:

> "No other occupants of the school bus suffered any injury beyond AIS-1 level. Some minor lacerations and abrasions were involved but the more general injuries are minor contusions."

The other two frontal collisions reported by the Univeristy of Toronto MDAI team, were with light vehicles and only "very few and only minor" injuries were produced. Again, no distribution of the injuries is offered.

In the United States (2), the same problem of lack of injury causation data exists. Data, when available tends to be fairly specific for vehicle involvement and number of passengers injured. This is standard police report data. But what body region was injured and how it was injured is not typically recorded. However, some localized (a few states) causal data is available (2).

Most reported injuries in school bus accidents occur to the head and face in frontal collisions and seat backs are the predominant source of injury in 70 - 90% of the injuries.

In a sample of 309 (2) minor to moderate injuries received in average accidents (e.g. no rare, severe accidents), the following observations were made:

a) Over 75% of all injuries were caused by the seat back;

b) Over 97% of all facial injuries in all types of collisions were caused by the seat back;

c) The seat back was responsible for 92.3% of all injuries received in frontal collisions;

d) 50% of these injuries were to the head;

e) Another 25% of these injuries were to the face;

f) The seat back was also responsible for 100% of the knee injuries, 80% of the leg injuries (only 4), 92% of the chest injuries, 88% of the arm and 52% of the shoulder injuries. Note that not all of these injuries were received in frontal collisions;

g) Five of the chest injuries against a seat back occured in frontal collisions.

In simple terms: in moderate accidents responsible for only minor and moderate injuries, the seat back is responsible for most injuries, is responsible for most injuries in frontal collisions, is responsible for most head and face injuries and is also responsible for virtually all chest injuries.

In another subset of 33 serious accidents (2), it was found that the seat was responsible for 54% (113) of the casulaties. In a subset of 47 serious school bus accidents, 38% (464) injuries were to the head and face and 16% (196) injuries were to the chest (impact location and collision type not given in either case).

Siegel et al (5) reported on a 1969 Maryland study in which:

a) 43.5% of the injured students received injuries only to the head;
b) 31% only to the chest;
c) 15% only to the legs;
d) 8.6% to the head and chest;
e) a total of 53% of the injuries were to the head and 28% were to the chest.

To summarize thus far: detailed injury causal data is scarce. However, where injuries are reported in detail, the majority of injuries discussed tend to be minor (AIS-1) (85%), a fair proporation are moderate (AIS-2) (11%). As many as 75% of all injuries are caused by the seat back and 97% of facial injuries and 60% of head injuries are caused by seat backs.

A survey conducted by the American Society of Oral Surgeons found that:

> "1,350 school children in school bus accidents required the services of an oral surgeon during a single school year. This would imply that as many as one-quarter of the pupils injured annually on school buses may receive facial injuries serious enough to require medical-dental treatment." (2)

Stansifer and Romberg (8) present an alarmist view that of a U.S. sample of general bus accidents, only 28% had ten or fewer injuries per bus, compared to their national average of 95% with ten or fewer injuries per vehicle. Unfortunately, what they fail to mention is that buses carry significantly more passengers than the national average "2.2 persons per car" and therefore significantly less accidents per passenger mile than the national average.

The scarcity and disparity of data combined with a sensitive issue, may paint a bleaker picture than acually exists. However, Boulay (7) reports in the U.S.A., that the school bus injury rate per passenger was only 3% that of all vehicles in 1973 while the school bus accidents to and from school are only 10% of all accidents while commuting to and from school.

Nevertheless, school bus seats and seat backs are responsible for at least 75% of all injuries received inside a bus, thus making this unit the most logical candidate for safety improvement.

CMVSS 222

Critical factors of pre-Motor Vehicle Safety Standard (MVSS) 222[6] school bus seats include:

1. Frames and anchorages; consisting of principally mild steel thin wall, tubular structures fastened to the floor with sheet metal screws; have proven

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6 While MVSS 222 denotes the safety standard in general, "CMVSS" relates to the Canadian Motor Vehicle Safety Standard and "FMVSS" relates to the United States Federal Motor Vehicle Standard.

incapable of supporting occupant loads in a crash situation. This results in seats becoming unhinged, seat backs bending or breaking too easily thereby removing the only restraint available to a passenger and encroaching into the survival space of another.

2. Seat backs which are too low also have the same effect as the above mentioned, as well as a capacity to inflict injury by its very location with respect to the head and face.

3. Seat backs have also been identified as hostile due to the lack of protective padding in areas where the head, face or knees might contact.

For these reasons, the performance requirements of CMVSS 222 focus on:

1. Seat and seat anchorage strength.
2. Seat back and restraining barrier (e.g. modesty panel) height and surface area.
3. Padding requirements of contactable surfaces of the seat back within the occupant seating area.

To be more specific, a description of CMVSS 222 will be given. It:

1. Defines a "survival space" for the passenger.

2. Defines which surface within the survival space must provide protection to the passenger.

For instance, it serves little purpose for the lower, front facing part of the seat back to provide head protection.

3. Specifies that school bus passenger seats must face the front of the bus.

Side facing seats, such as those found on city buses, place the passenger in a less desirable position (relatively unsafe). It would likely also be difficult to have children sit properly in rear facing seats, and whiplash potential could also be increased.

4. Specifies the width of a seating position on a seat as fifteen inches.

5. Specifies the minimum height of the seat back as twenty inches above the seating reference points.

6. Specifies the minimum area of a seat back as a percentage of seat back height and seat width.

This, in effect, limits the allowable taper of a seat back, thus protecting the passenger from pronounced "edge effects".

7. Specifies forward and rearward loading performance characteristics of a seat back or restrainig barrier (modesty panel).

This part of the standard verifies for seat integrity, specifies maximum allowable deflections of the seat and seat back, as well as force/deflection characteristics in forward bending and maximum strength (stiffness) in rearward bending. The object is to ensure that a seat assembly is strong enough to support and restrain occupant(s) within their survival space, while ensuring that sufficient flexibility is present to give a safe "ride-down" from an impact.

8. Specifies performance requirements for head and face protection.

The test consists of having an 11 1/2 lb. head form test device strike any "contactable surface" within the "head protection zone" at one of two specified impact velocities. At the high impact velocity (22fps) the deceleration of the center of gravity must be such that the HIC value is less than 1,000. This is intended to ensure that at this velocity, no threat to head protection exists. The validity of this criterion has often been questioned and is in doubt (10). In fact, in 1979, Zimmerman (11) reported on tests in which pre-MVSS 222 school bus seats with and without any extra padding

were impacted in a manner conforming to MVSS 222. He found that seats equipped with retrofit materials met this criterion. He also found that all impacts directly against the metal cross bar also produced results of HIC <1,000! Perhaps this part of the standard should be re-examined.

At high speeds, the seat back must be able to absorb at least 40 in/lb of energy before the load on the test device reaches 150 lbs. This criteria addresses the face protection capabilities of the seat and is presumably to guard against broken teeth and facial bones.

At low speeds (5fps), the head form must produce in the "contactable surface", a contact area of not less than $3in^2$. This is to guard against the possibility of lacerations and contusions. It is not clear how the size of the indentation is measured.

Oddly enough, Zimmerman also reports that in terms of maximum force, maximum acceleration and pulse duration, the effects of extra padding are minor. The padding did however affect the onset slope of the load application curve enough to allow compliance with the high speed face injury criterion.

9. Specifies performance requirements for knee and leg protection.

The standard specifies that a knee form test device, impacting a seat back or restraining barrier anywhere within the "leg protection zone" at a medium (16fps) velocity shall not "feel" more than a 600 lbs. load and shall have a contact area of at least $3in^2$. A 600 lb. resistance force is quite adequate as it appears to be well below currently discussed tolerance levels ranging up to 5,000 lbs. (12)

To conclude, there are four characteristics which distinguish seats that comply with CMVSS:

- The seats have been repositioned such that the rear surface of another passenger seat is no more than twenty-one inches from the seating reference point. In any case, including the front seat, there is a restraining barrier no more than twenty-one inches from the seating reference point. This has generally resulted in seats being positioned closer together in order to reduce "occupant slap";
- Extra padding has been installed in the seat;
- The seat back height has been raised;
- The seat back support, anchors and seat structure must meet specific loading requirements.

EFFECTS, POTENTIAL AND REAL, OF CMVSS 222

Literature documenting the benefits of seats complying with the CMVSS 222 simply does not exist. However, in 1975, a California survey (7) revealed that out of 5,400 school buses, 825 were equipped with seat pads.[7] Thirteen (1.6%) of these 825 buses were involved in accidents.

These accidents resulted in twenty-five injuries (17 head and 8 chest injuries). The author estimates that 121 other occupants of these buses escaped injury because of the pads.

The same study reports on 16 additional buses in which every second seat was retrofitted with "Facesaver" [8] pads. Over a six month period, 3,275,906 pupil transportation hours were accumulated. No accidents occured. However, in two hard braking situations, the pads are credited for saving two children from receiving facial injuries.

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7 This is the result of a 1972 California State law requiring new buses to be equipped with seat back padding.

8 Manufacturer and origin unknown.

Cost per injury saved are reported by the author as being $397.00 U.S. for the buses in the survey and $112.00 U.S. for the 16 bus pilot projects.

In 1980, Northrop et al, reported on an analysis where MDAI reports from across the U.S.A. and Canada were studied and clinically analysed to establish, for all recorded injuries, the expected outcome had FMVSS 222 compliant seats been used. (9)

Their analysis was broken into two categories: non-fatal school bus accidents and school bus accidents where fatalities occured. This break down was necessary as accidents resulting in fatalities are, by nature, very violent and not at all representative of the average school bus accident.

For non-fatal accidents, their sample consisted of 56 accidents involving a total of 1,688 passengers (30 passengers/bus). The injured numbered 719 (42.6%), an average of 12.8 injured per accident.

By breaking down and analysing the sample, and then

applying the results to a balanced[9] national average, they show that:

- 68% of OAIS[10] 1 injuries would be reduced to no injuries;
- 42% of OAIS 2 injuries would be reduced to OAIS 1 injuries;
- 40% of OAIS 2 injuries would be reduced to no injuries;
- 51% of OAIS 3 injuries would be reduced to OAIS 2 injuries;
- 51% of OAIS 4 injuries would be reduced to OAIS 3 injuries.

The authors warn that due to a lack of data, these last two are but conservative estimates.

With these results, they suggest that 34% of all accidents occuring before the inception of MVSS 222 would not have been reported as passenger injury

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9 They also that the accidents reported by the MDAI teams are much more severe, than the average. They also report that on a national basis the number of passengers injured per accident is closer to 1.4 rather than 12.8.

10 OAIS: overall AIS, from the 1976 AIS.

accidents, 65% of the injured students would not have been injured and 4% would have had their OAIS 2, 3 or 4 injury reduced by at least 1 level. Thus, 69% of the injured passengers would have fared better. Coincidentally, Gow and Steiner (4) in 1979, predicted that as many as 70% of all injuries caused by contact with seats or seat members, would be eliminated or reduced to "complaints of pain".

For school bus accidents involving fatalities, Northrop et al's sample comprised 26 MDAI school bus reports in which there were: 712 passengers (27.4 passengers per accident), of whom 83 (11.6%) were killed and 490 (68.8%) were injured. This gives a rate of 3.2 passengers killed per accient as compared to the U.S. national average of 1.8 killed per accident; once again, showing that MDAI reports tend to be biased towards worst case situations. Of these fatalities, 87% occured in side impacts or rollovers; collisions in which seats complying or not to MVSS 222 make little difference. Conversely, no fatalities were recorded in rear ends, head ons or accidents in which the buses broadsided other vehicles.

Only seven (8.4%) of the 83 fatalities were judged by the authors to be potentially non-fatal. Six of these seven fatalities occured in vans where no seat belts were present. They assumed that had the vans met the standard, seat belts would have been installed and properly worn.

It was estimated for the seventh, whose death was the result of massive abdominal damage received against the top of a seat back of a conventional bus, that his injuries would have been limited to a OAIS 2 or less.

Because most of the fatalities that could have been averted occured in vans, and because some of these vans were equipped with seat belts that were not worn, the fatality reduction estimate is decidedly low. In Canada, where seat belt legislation exists in many provinces, and where belt usage is more common, this estimate would be higher.

They conclude, for school bus accidents in which fatalities occured, that: 7% of the fatalities would be averted, 17% of the injured passengers would be reduced to No-injury and that overall, 29% of the injured passengers in these accidents would have had their OAIS level decreased by 1.

CONCLUSIONS

Statistics have shown that overall, school buses are a very safe mode of travel. Even accident and injury figures before the inception of CMVSS 222 are far below the national statistics. It has also been shown that CMVSS 222 has the potential for reducing a great deal of the number and severity of injuries that occur presently in school bus accidents.

Even Sansifer and Romberg's alarmist view presented earlier is moderated by their conclusions that seat belts should not be installed on buses as they can only be cost effective with over 80% usage rates (they predict that, on a volunteer basis, only 10 - 20% usage rates would exist). They go on to recommend that energy management should be an integral part of the seat and that only slight modifications are required to "maximize restraint value and minimize injury producing potential".

Nevertheless, school buses typically have a lifespan of ten years and CMVSS 222 has only been implemented since 1979. Therefore, a fair proportion of pre-CMVSS 222 buses are still in circulation (it is fair to assume however that the newer buses get the most use; the older

ones being kept as back-ups). Furthermore, the queston "What if there was more protection?" is a valid one.

Zimmerman (11), in 1979, concluded that fairly standard materials are available that would allow retrofit of school bus seats to allow them to meet at least the dynamic portion of CMVSS 222. The materials that he used in testing, as well as their suitability, is outlined in table 9. Undoubtedly, these are but a few of the materials that could be used for that energy absorbtion. Others, such as neoprene, styrene, urethane or propylene, might conceivably be used. Factors determining suitability, such as: price, availability, performance, durability, thickness, etc., would determine the final choice.

TABLE 9

CANDIDATE RETROFIT MATERIALS

MATERIAL	GRADE	THICKNESS (in inches)	SUITABLE
PVC-Koroseal	M455	1/2	NO
PVC-Rubatex	310	1	YES
Expanded PVC-Ensolite	AA	1-1 1/4	YES
Polyethylene Foam-Ethafoam	220	1-1 1/4	YES
Wool Felt	SAE F-10	1	NO

Based on the laboratory tests, Zimmerman also concluded that:

- The contact area requirement of MVSS 222 head and knee form tests were the least reliable in judging suitability;
- The seat back rail and modesty panel are the most dangerous objects for potential facial injuries. Stanchions appeared less dangerous for the face but more so for the knees;
- "Head-concussion type injuries do not appear to be a problem with older model school bus seats. These include tests on seat backs, seat back rails, modesty panels and stanchions without padding. Modesty panel rails produced the highest results."

Unfortunately, this last conclusion may be more of a reflection of a poor injury criterion than of a safe environment.

And finally, it is disconcerting to note the number of accidents that are as a result of bus driver error or mechanical failure.

RECOMMENDATIONS

1. It would be interesting, if not at least necessary, to verify Northrop et al's predictions for injury reduction as a result of the implementation of CMVSS 222.

2. Provision of protection equal to that required by the dynamic portion of CMVSS 222 should be conveniently made available to those desiring it.

3. An inventory of pre-CMVSS 222 buses should be done. Their rate of removal from service should also be assessed. Further decisions should be based on these findings as well as those of #1.

4. Vehicle inspection procedures should be assessed, with the possibility of them being upgraded, standardized and/or mandated.

5. Driver training procedures should be assessed, with the possibility of them being upgraded, standardized and/or mandated.

6. The rate of removal of pre-CMVSS 222 school buses could be accelerated.

7. Safety and injury potential of small (Van) buses should be assessed. They behave more like cars than traditional school buses and should be treated as such without negating any of the benefits accorded to them by CMVSS 222.

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APPENDIX "A"

"School Bus Passenger Seating and Crash Protection

SOR 80-161 eff 9-80

222. (1) In this section,

"contactable surface" means any surface within the head protection zone that is contactable from any direction by a head form test device, except any surface on the front of a seat back or restraining barrier 76 mm (3 inches) or more below the top of the seat back or restraining barrier;

"head protection zones" means the spaces in front of each school bus passenger seat that are not occupied by any sidewall, window or door structure and that, in relation to that seat and its seating reference point, are enclosed by the following planes:

(*a*) horizontal planes 300 mm (12 inches) and 1 016 mm (40 inches) above the seating reference point,

(*b*) a vertical longitudinal plane tangent to the inboard (aisle side) edge of the seat,

(*c*) a vertical longitudinal plane 83 mm (3.25 inches) inboard of the outboard edge of the seat, and

(*d*) vertical transverse planes through and 760 mm (30 inches) forward of the seating reference point;

"leg protection zones" means those parts of a school bus passenger seat back or restraining barrier that are bounded by horizontal planes 300 mm (12 inches) above and 100 mm (4 inches) below the seating reference point of the school bus passenger seat immediately behind the seat back or restraining barrier;

"school bus passenger seat" means a seat in a school bus, other than the driver's seat or a seat that is installed to accommodate a handicapped or convalescent passenger and is oriented in a direction that is more than 45 degrees to the left or right of the longitudinal centre-line of the vehicle.

(2) Every school bus shall, when subjected to Motor Vehicle Safety Test Methods, Section 222, School Bus Passenger Seating and Crash Protection, (September 1, 1979) meet, at all designated seating positions other than the driver's seat, all the requirements of subsections (6) to (12).

(3) A passenger seat in a school bus need not meet further test requirements after having been subjected to and having met the requirements of subsections (6) and (9) and any one of subsections (7), (8), (11) and (12).

(4) Every school bus passenger seat shall face the front.

(5) The number of seating positions in a bench type seat shall be obtained by dividing the bench width measured in millimetres or inches by 381 mm or 15 inches, as the case may be, and rounding the quotient to the nearest whole number or, if the quotient is equidistant from two whole numbers, to the higher thereof.

(6) Every school bus passenger seat shall be equipped with a seat back having

(*a*) a height not less than 508 mm (20 inches) above the seating reference point; and

(*b*) a front surface area of not less than 90 per cent of the seat bench width measured in millimetres or inches multiplied by 508 mm or 20 inches, as the case may be, that is

(i) above the horizontal plane that passes through the seating reference point, and

(ii) below the horizontal plane that passes through a point 508 mm or 20 inches above the seating reference point.

(7) Where a school bus passenger seat that has another seat behind it is subjected to forward performance tests as specified in the test methods referred to in subsection (2)

(*a*) the seat back force/deflection curve shall fall within the zone specified in Figure 1;

(*b*) the seat back deflection shall not exceed 356 mm (14 inches);

(*c*) the seat shall not deflect by an amount such that any part of the seat moves to within 100 mm (4 inches) of any part of another school bus passenger seat or restraining barrier in its originally installed position;

(*d*) the seat shall not separate from the vehicle at any attachment point; and

(*e*) the seat components shall not separate at any attachment point.

(8) Where a school bus passenger seat that has another seat behind it is subjected to rearward performance tests as specified in the test methods referred to in subsection (2),

(*a*) the seat back force shall not exceed 9 876 N (2,200 pounds);

(*b*) the seat back deflection shall not exceed 250 mm (10 inches);

(*c*) the seat shall not deflect by an amount such that any part of the seat moves to within 100 mm (4 inches) of any part of another school bus passenger seat in its originally installed position;

(*d*) the seat shall not separate from the vehicle at any attachment point; and

(*e*) the seat components shall not separate at any attachment point.

(9) No seat cushion with which a school bus passenger seat is equipped shall, where all the manual attachment devices between the seat and the seat cushion are in the manufacturer's designed position for attachment, separate from the seat at any attachment point when subjected to an upward force of five times the seat cushion weight, applied in any period of not less than 1 nor more than 2 seconds, and maintained for 5 seconds.

(10) A restraining barrier shall be provided forward of any designated seating position that does not have the rear surface of another school bus passenger seat within 533 mm (21 inches) of seating reference point, measured along a horizontal line through the seating reference point in the forward direction, such that

(*a*) the horizontal distance between the restraining barrier's rear surface and the seating reference point of the seat in front of which it is required shall be not more than 533 mm (21 inches);

(*b*) the position and rear surface area of the restraining barrier shall be such that, in a front projected view of the bus, each point of the barrier's perimeter coincides with or lies outside of the perimeter of the seat back of the seat for which it is required; and

(*c*) when subjected to a forward force, as specified in the test methods referred to in subsection (2), shall meet all the requirements specified in paragraphs 7(*a*), (*b*), (*d*) and (*e*) as they apply to a seat, and the restraining barrier deflection shall not interfere with normal door operation.

(11) When any contactable surface of a school bus within the head protection zones is impacted from any direction by a head form test device, as specified in the test methods referred to in subsection (2),

(*a*) at 6.7 m/s (22 feet per second),

(i) the axial acceleration at the centre of gravity of the head form test device shall be such that the expression

$$\left[\frac{1}{t_1-t_1}\int_{t_1}^{t_2} a\,dt\right]^{2.5}(t_2-t_1)$$

shall not exceed 1,000, where "a" is the axial acceleration expressed as a multiple of "g" (the acceleration due to gravity), and t_1 and t_2 are any two points in time during the impact, and

(ii) the energy necessary to deflect the impacted material shall be not less than 4.52 Nm (40 inch-pounds) before the force level on the head form test device exceeds 667 N (150 pounds); and

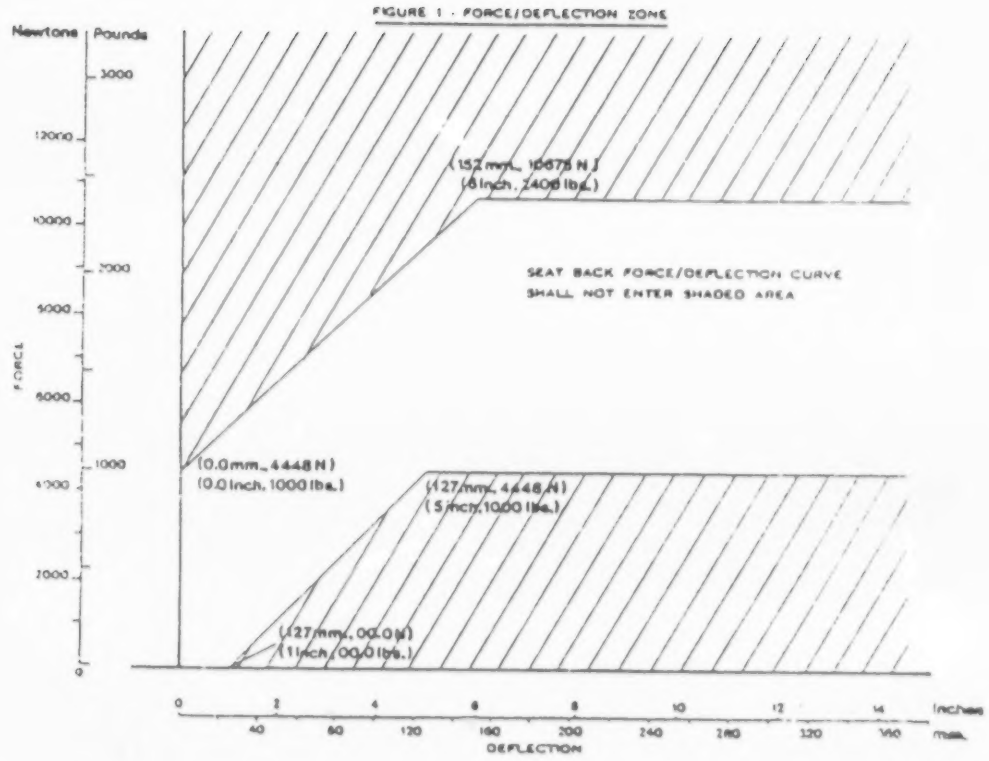
(*b*) at 1.5 m/s (5 feet per second) the contact area on the head form test device surface shall not be less than 1 935 mm² (3 square inches).

(12) When any point on the rear surface of a part of a seat back or restraining barrier within the leg protection zone is impacted from any direction by a knee form test device, as specified in the test methods referred to in subsection (2) at 4.88 m/s (16 feet per second)

(*a*) the resisting force of the impacted material shall not exceed 2 669 N (600 pounds); and

(*b*) the contact area on the knee form test device surface shall not be less than 1 935 mm² (3 square inches)."

FIGURE 1 - FORCE/DEFLECTION ZONE



Appendix C

Laboratory Evaluation of Contemporary School Bus Seats

LABORATORY EVALUATION OF

CONTEMPORARY SCHOOL BUS SEATS

Submitted to

TES Limited
Ottawa, Ontario

Prepared by

Andre St-Laurent
Biokinetics and Associates Limited
Ottawa, Ontario

March, 1984
Document R84-5A

INTRODUCTION

A thorough literature review[1] revealed that the major source of injuries to school children in school buses, during a school bus accident, is the seat back. The study also showed that the most common injuries were cuts, scrapes and bruises to the face.

TES Limited, under TDC sponsorship, has commissioned Biokinetics and Associates Limited to conduct a series of laboratory tests to investigate the propensity of a number of school bus seats to inflict facial injury in a crash situation.

SEATS TESTED

Eight seat/seat add-on combinations were part of this test series. The basic seats were:

1. A pre 1975 seat. The seat is characterized by a low seat back, and the seat back's metal frame and screws are exposed.
2. A pre CMVSS seat. This seat, typically installed on school buses between 1975 and 1979, is characterized by a higher seat back and a padded metal frame.
3. A post CMVSS seat. This seat is characterized by a higher seat back than the pre CMVSS, better (more) protective padding around the seat frame, padding of the seat back area and metal gussets at the base of the seat back; all of which permit this type of seat to meet or exceed the requirements of CMVSS 222.

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1 St-Laurent, Andre, "School Bus Accidents and Passenger Injuries - A Literature Review -" Biokinetics and Associates Report R83-14A, Submitted to TES Limited, September, 1983

As attachments and add-ons to the three basic seats, two retrofit kits, as well as a portable, removable cushion, were provided to complete the test matrix. The seat/add-on combinations used were:

4. A commercial retrofit kit designed to fit to the pre 1975 seat;
5. A prototype retrofit kit designed and built by TES and fitted to the pre CMVSS seat;
6. The same retrofit kit but attached to a post CMVSS seat;
7. A prototype, portable safety cushion, provided by Dr. Katz of Montreal, affixed to the pre CMVSS seat; and
8. The "Katz Cushion" affixed to a post CMVSS seat.

TEST RATIONALE

The purpose of these tests was to establish the relative propensity of the above eight seats to induce facial injury in frontal crash situations.

CMVSS 222 is the standard which governs the performance of modern (post 1979) school bus seats. It addresses aspects of a school bus seat when viewed as a restraining barrier. As such, the standard focuses on:

1. Seat and seat anchorage strength;
2. Seat back and restraining barrier (i.e. modesty panel) height and surface area;
3. Seat back and restraining barrier rigidity (e.g. stiff enough to support the impact load of the passengers behind it; and
4. Padding requirements of the contactable surfaces of the seat back within an "occupant seating area".

The first three aspects are very relevant to occupant protection but not particularly to the mitigation of facial injuries. The fourth aspect of CMVSS 222 relates more to head injury protection than to facial injury protection.

Because pre CMVSS 222 seats, even equipped with added protection would fail at least some requirement of CMVSS 222 and the equipment needed to conduct such a test was not readily available; and principally because the primary concern with school bus seats in accident situations is with facial injuries and not with head injuries; it was decided that the test program would not resemble the methods used in CMVSS 222.

What was required was a test that could measure the risk of a facial injury, monitor the severity of the impact, and be relatively insensitive to seat back flexion and seat anchorage.

TEST METHOD

The method used involved impacting a seat back at given velocities with a state-of-the-art frangible face/headform assembly of approximately 5 Kg mass. The impact velocities were increased until either the frangible facepiece broke or the test equipment's maximum attainable velocity was reached.

The seat back was horizontally positioned and rested firmly on a rigid base, thereby negating geometric and mechanical factors such as seat back height and flexibility. The seats were aligned such that the metal cross bar of the seat frame would impact against the nasion (bridge of the nose) of the head form. This alignment can be seen in Figure 1 wherein the Hybrid III headform, fitted with its regular skin, is resting against a pre 1975 seat.

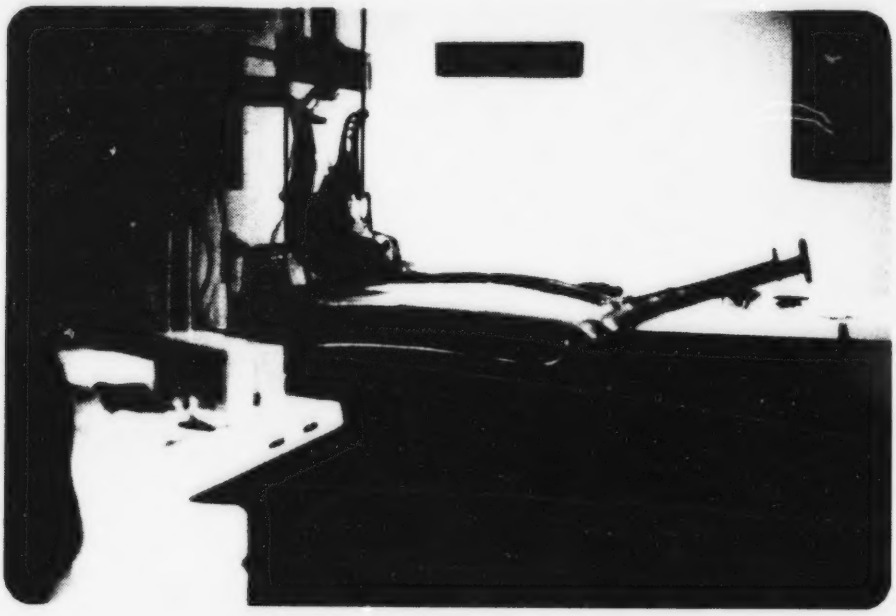

FIGURE 1: Hybrid III Headform with Skin Covering Aligned with Metal Frame of pre 1975 Seat

Although head injuries are not common in school bus accidents, it was felt that at higher impact velocities, the foam padding could tend to "bottom out" thereby increasing the likelyhood of brain injury, even if the loads were sufficiently distributed to preclude facial injury. Therefore, head

acceleration during impact was also monitored; but more as a back-up quantity and system check than as the primary measured quantity.

EQUIPMENT

The headform used for testing was a General Motors Hybrid III anthropometric test device (ATD) headform. As part of an earlier study, the facial section of the metal headform had been removed and replaced with a Methyl Methacrylate counterpart (Figure 2) to simulate the facial bones. The facepiece and an RTV silicone backing (Figure 3) are tailored such that when impacted, at critical levels, the facepiece fractured at levels similar to those of the bones of a human face. The standard Hybrid III skin was replaced by approximately 7 mm of pure gum rubber in order to provide the assembly with the proper, repeatable, cushioning properties such as those found in human adipose tissue.

FIGURE 2: Modified Hybrid III Headform with Frangible Facepiece Installed

The desired impact velocities were reached by allowing the headform assembly to drop in guided free fall from specified heights. The acceleration was measured by a B&K accelerometer (model 4369) and, after conditioning, was displayed on a Tektronix oscilloscope (Model 5111).

FIGURE 3: Modified Hybrid III Headform Without Facepiece

RESULTS

In four of the eight tests the facepiece fractured completely (Figure 4). The seats involved were:

1. Pre 1975;
2. Pre 1975 with Retrofit;
3. Pre CMVSS; and
4. Post CMVSS.

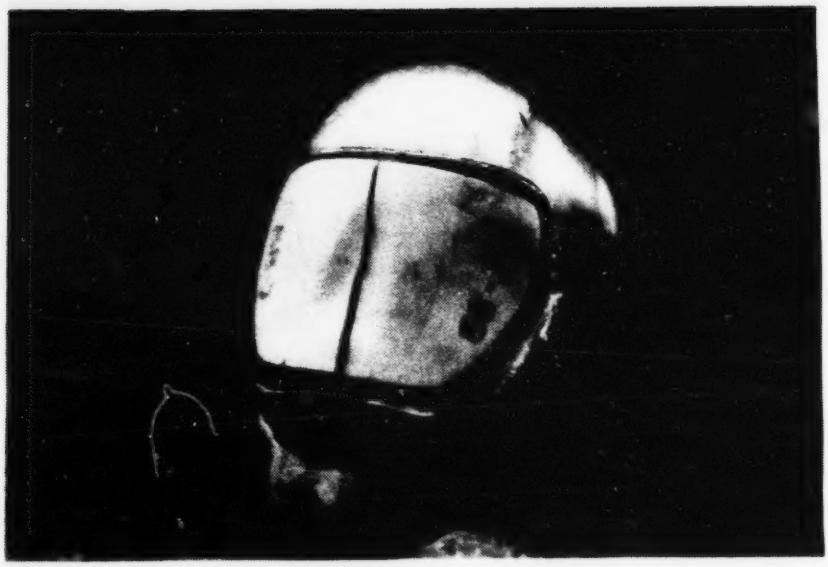

FIGURE 4: Fractured Facepiece After Pre 1975 With Commercial Retrofit Test

In four of the remaining tests, the impact velocity reached its maximum and no facepiece fractured. The seats in this category were:

1. Post CMVSS;
2. Pre CMVSS with TES retrofit;
3. Post CMVSS with TES retrofit;
4. Pre CMVSS with Katz Cushion; and
5. Post CMVSS with Katz Cushion.

The post CMVSS seat was tested twice at a maximum impact velocity of 28.5 km/h. In one case, the facepiece did not break, in the other, a crack developed in the facepiece but did not fracture completely into the characteristic left and right halves (Figure 5). It therefore fits into both of the previous categories. In no case did the foam padding on any of the seats "bottom out".

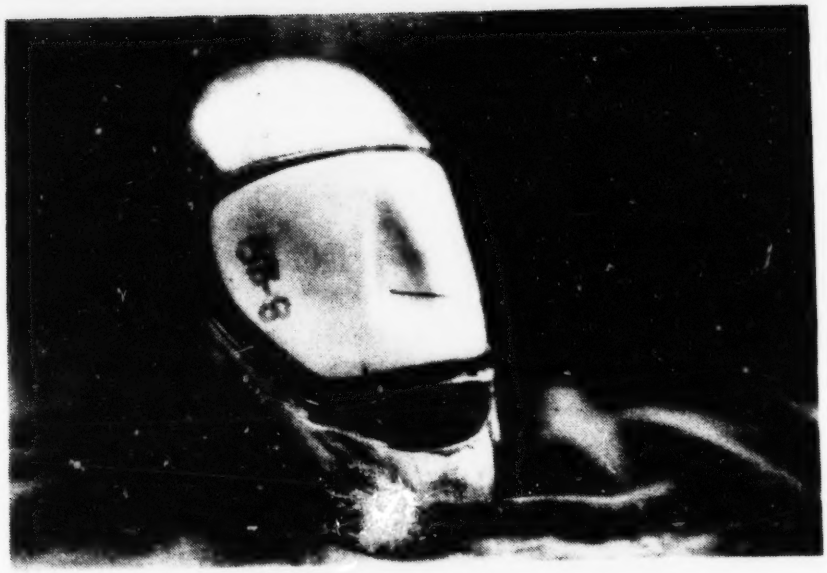

FIGURE 5: Partially Fractured Facepiece After Post CMVSS Seat Test

The complete list of results are presented in Figure 6. The results are summarized in Table 1 and Figure 7. Figure 6 presents the maximum head acceleration versus the impact velocity for each test. Each type of marker denotes one of the following seat configurations:

1. Seat without any options;
2. Seat with a retrofit kit; or
3. Seat with the Katz cushion.

The different line types used provide reference to the type of seat used:

1. Pre 1975;
2. Pre CMVSS; or
3. Post CMVSS.

Figure 7 shows the maximum velocity to which each seat was tested before either the occurance of facepiece fracture or maximum test impact velocity.

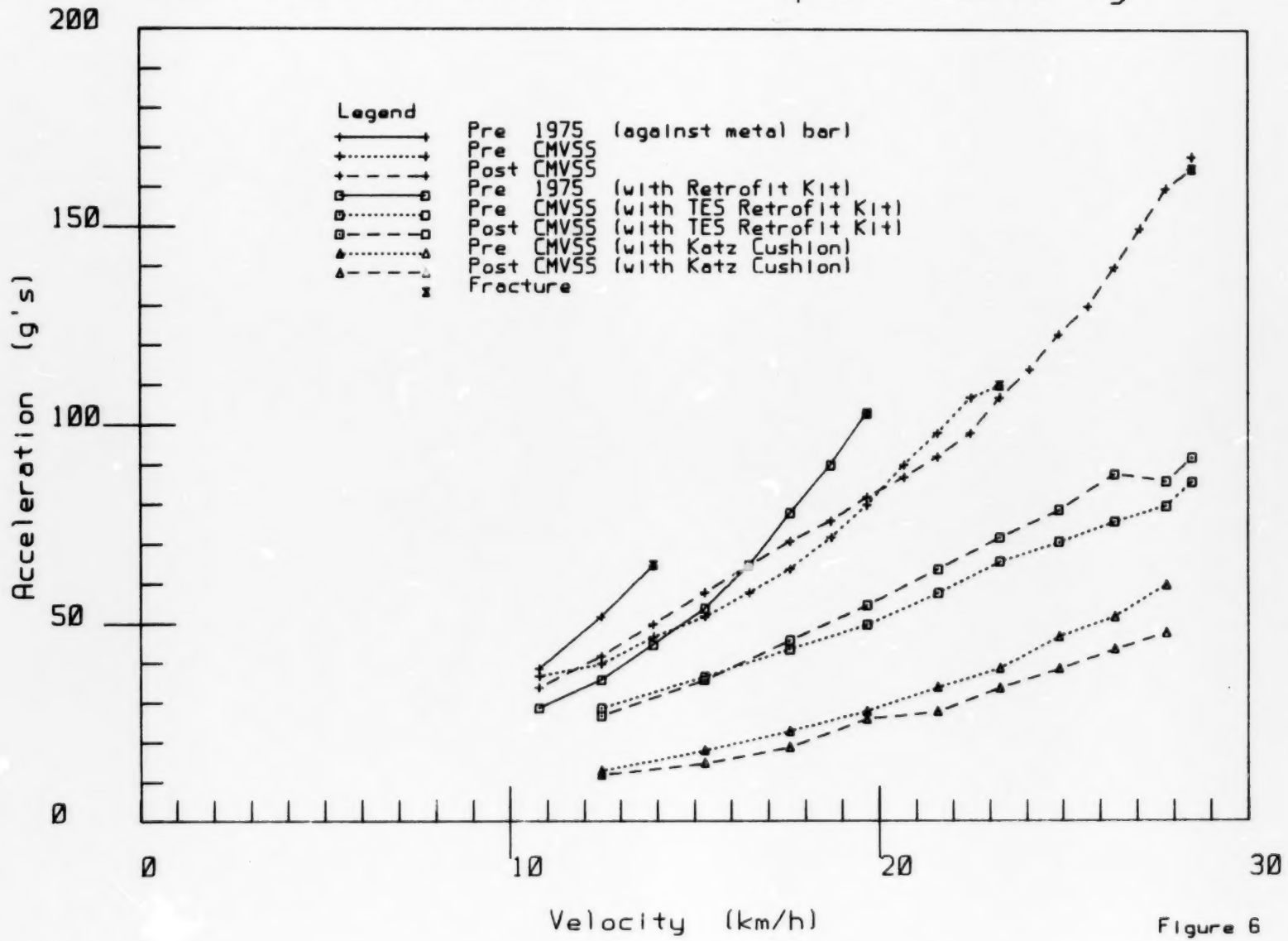
Head Acceleration Vs Impact Velocity
Legend
Pre 1975 (against metal bar)
Pre CMVSS
Post CMVSS
Pre 1975 (with Retrofit Kit)
Pre CMVSS (with TES Retrofit Kit)
Post CMVSS (with TES Retrofit Kit)
Pre CMVSS (with Katz Cushion)
Post CMVSS (with Katz Cushion)
Fracture
Acceleration (g's)
200
150
100
50
0
0
10
20
30
Velocity (km/h)

Figure 6

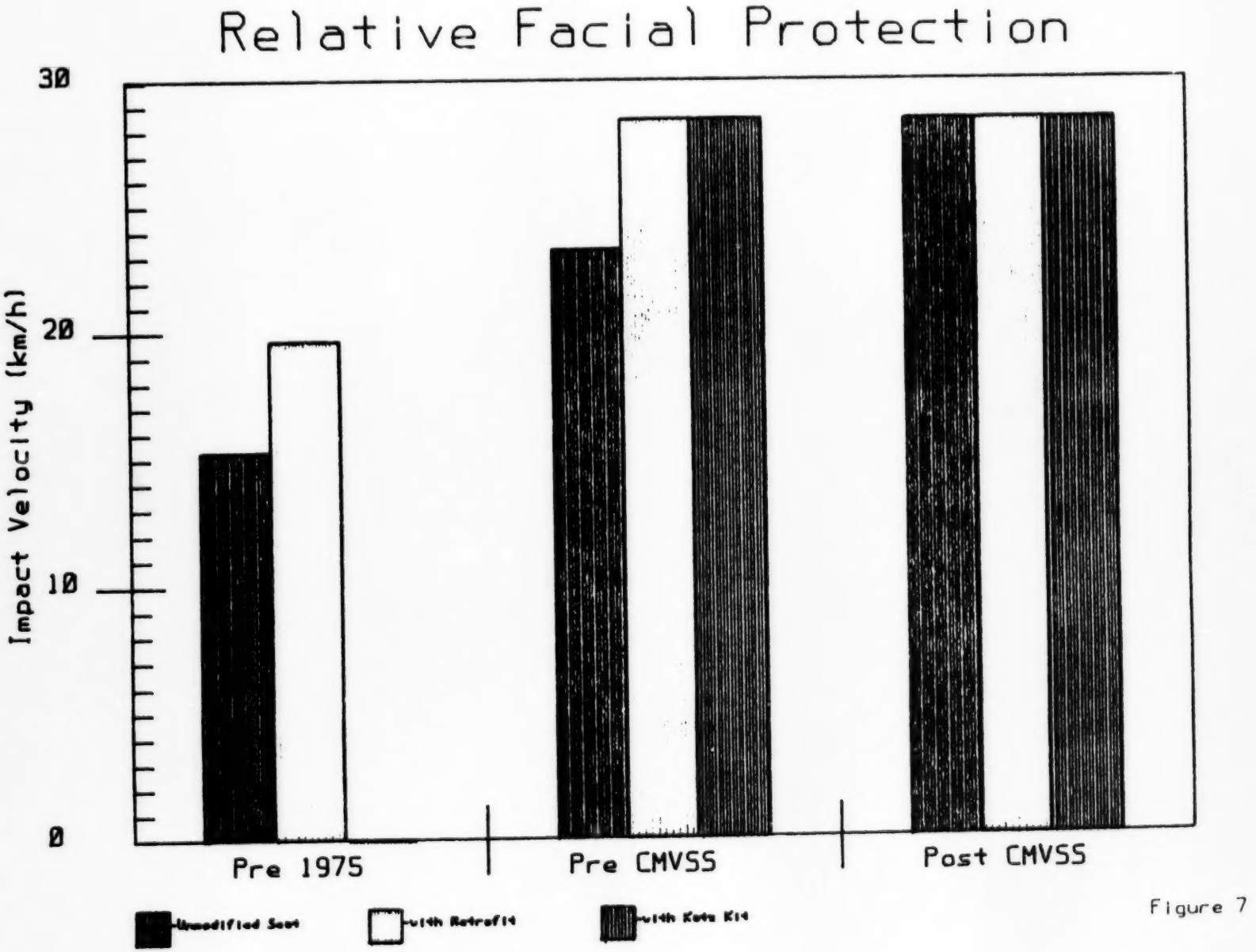
Relative Facial Protection
30
20
10
0
Impact Velocity (km/h)
Pre 1975
Pre CMVSS
Post CMVSS
Unmodified Seat
with Retrofit
with Kats Kit

Figure 7

Table 1

RESULTS OF SCHOOL BUS SEAT BACK TEST PROGRAM

SEAT	IMPACT VELOCITY (km/h)	MAXIMUM POSSIBLE VELOCITY	FACE FRACTURE	MAXIMUM ACC'N (g's)
Pre 1975 (Against metal bar)	13.9	N	Y	65
Pre CMVSS	23.3	N	Y	110
Post CMVSS	28.5	Y	N/Y*	168/165*
Pre 1975 (With Retrofit)	19.7	N	Y	103
Pre CMVSS (With TES Retrofit)	28.5	Y	N	86
Post CMVSS (With TES Retrofit)	28.5	Y	N	92
Pre CMVSS (With Katz Cushion)	27.8**	Y	N	60
Post CMVSS (With Katz Cushion)	27.8**	Y	N	48

* Two tests
** Due to the thickness of the Katz Cushion, the maximum impact velocity was slightly lower.

DISCUSSION

Three seats performed poorly. They were:

1. Pre 1975 (against a metal bar);
2. Pre 1975 (with retrofit); and
3. Pre CMVSS

When tested, these seats caused the facepiece to fracture at energies far below the maximum test impact velocity that what all other seats were able to withstand.

The maximum test impact velocity, approximately 28 km/h, is close to the velocity change which a passenger would experience in a severe 40 to 50 km/h head on collision with a vehicle of equivalent mass and oncoming velocity.

In contrast, the Canadian Standards Association (CSA), specifies an impact velocity of about 25.2 km/h in a section of its D230 Draft Motorcycle Helmet Standard. Furthermore, it specifies that a helmet shall fail the test if the headform (similar to the one use for this test series) undergoes an acceleration greater than 300 g's.

Granted, CSA D230 is a standard designed to protect motorcyclists against head injury, but the fact remains that in our testing, at velocities approximately 3 1/2 km/h greater (a significant difference) none of the five "good" seats approached the 300g limit, and four of the five seats (Post CMVSS excepted) were soft enough to prevent even facial bone fracture.

As previously mentioned, seat back flexion was not considered in this test program. In a school bus, in an accident situation, one may assume this effect to be beneficial to an occupant by providing a greater "ride down" distance than that available from foam crush alone.

Given the low probability of facial injury for the five good seats, any further ranking has to be based on maximum head acceleration values. This value gives an indication of the probability of head injury. Although maximum head acceleration values are quite different for the different

types of "good" seats, further ranking may be somewhat meaningless since all maximum head acceleration levels are below accepted head injury tolerance levels.

It should also be noted that seat back padding "bottoming out"[2] mentioned earlier did not manifest itself in this test programme thereby allowing one to infer that at greater impact velocities, head accelerations would continue to increase more or less linearly.

Notwithstanding, the five good seats may be ranked as follows:

GROUP ONE

1. Post CMVSS (with Katz Cushion);
2. Pre CMVSS (with Katz Cushion);

GROUP TWO

3. Pre CMVSS (with TES Retrofit);
4. Post CMVSS (with TES Retrofit);

GROUP THREE

5. Post CMVSS.

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2 "Bottoming out" is a term used when foam has completely crushed and has in effect become "solid", thereby losing any ability to further absorb energy. Typically when this phenomenon occurs, a small increase in impact energy will produce a large increase of head accelerations. Head acceleration values of 700 - 1,000 g's and more are not uncommon.

CONCLUSIONS

It is fairly obvious that the greater the amount of padding on a seat back, the softer the blow will be. Figure 6 attests to this quite readily. It is seen that seats equipped with the TES retrofit (square markers) induce head accelerations roughly twice those of the seats equipped with the Katz cushion (triangular markers), and seats without any added protection (the CMVSS 222 seat, + markers), induce head accelerations roughly twice again those of TES retrofit equipped seats.

What is not so obvious is that extra padding is not required to provide adequate protection in frontal collisions, on buses equipped with seats meeting the requirements of CMVSS 222. For even if during testing the facepiece fractured on the post CMVSS seat, it did so at impact energies considerably higher than might be expected in a school bus crash. At these high impact velocities, one could expect injuries to occur, but not necessarily against the seat back. The windows and side walls still provide an aggressive structure, which on rebound, or even on primary impact, is quite capable of inducing serious injury.

The commercial retrofit kit attached to the pre 1975 seat provides inadequate added protection. Conversely, the TES retrofit kit added to the existing protection of the pre CMVSS seat provides more than adequate impact protection.

The Katz cushioned performed the best overall, but its ability to remain in the proper position during an accident is seriously questionned by this

author. Furthermore, in light of the performance levels of the post CMVSS seat and the seats equipped with the TES retrofit kit, the Katz cushion would seem to fulfill a non-existent need.